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1. Climate Scenarios

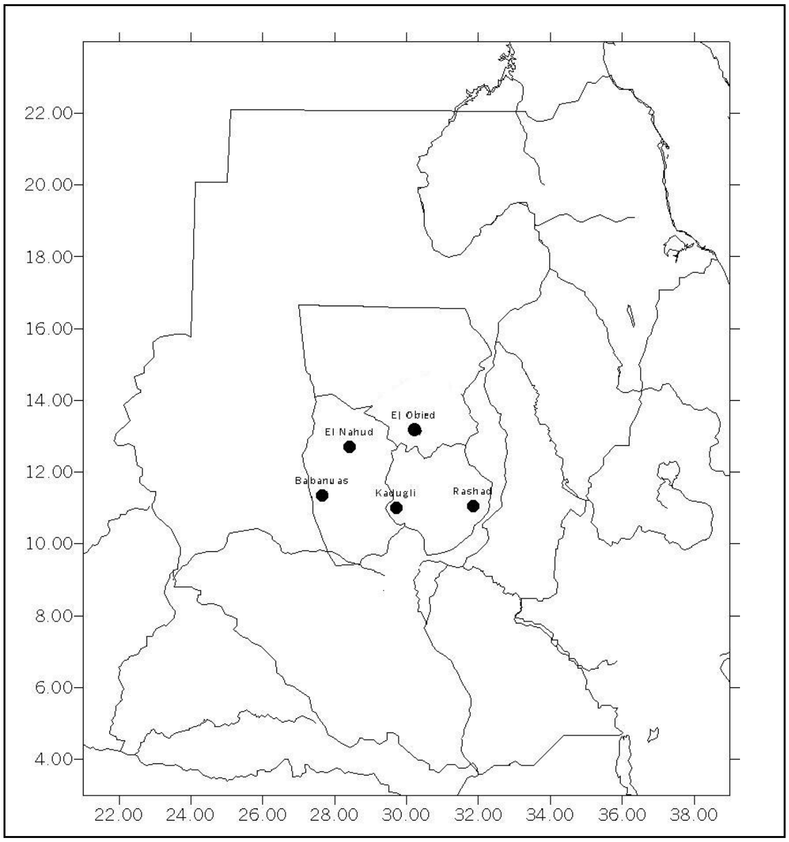
The purpose of developing future scenarios of climate is to enable a comparison between a future in which climate change does not play a role (the baseline scenario) and a future in which climate change is in effect (the climate change scenario). This comparison allows for an assessment of the potential future impact of climate change on the sector of interest. The methods for developing these two scenarios are described in Chapter 3 and below.

For this assessment, scenarios (both baseline and climate change) have been developed for each of the five climate stations, to allow for adequate representation of Kordofan's varied climate. The table below provides location and altitude of the stations; the accompanying map illustrates these locations.

Table 1.1: Locations of selected stations

Station	Latitude	Longitude	Altitude (meters) above mean sea level
EL OBEID	13º 10' N	30 º14 E	570
EN NAHUD	12º 42' N	28 º26 E	565
RASHAD	11º 52' N	31 º03 E	885
KADUGLI	11º 00' N	29 º43 E	500
BABANUSA	11º 20' N	27 º40 E	543

Figure 1.1: Location of Kordofan Region within Sudan



Milestone years 2030 and 2060 have been used in place of IPCC-proposed 2015, 2050, and 2100.

1.1 Baseline scenario

In impact assessment, it is typical to use a period of years of observed meteorological data to define a future baseline climate scenario. Taking this approach, baseline climate scenarios for both temperature and precipitation were developed for each of the five stations, using the 30-year averages of actual, monthly meteorological observations for the period 1961-1990.

In addition to IPCC recommendations, the following criteria were considered in the selection of 1961-1990 as the baseline climate scenario for

Kordofan Region:
Representative of the present-day or recent monthly average climate in the study region.
Of sufficient duration to encompass a range of climatic variations, including number of significant weather anomalies (i.e. sever droughts or warm season).
Covers a period for which data on all major climatological variables are abundant, adequately distributed and readily available.
Includes data of sufficient quality for use in evaluating impacts
Is consistent or readily comparable with baseline climatology used in other impact assessments.

For a complete discussion of the baseline scenario selection process, see Chapter 3 (section 2).

Limitations: A number of limitations and uncertainties were encountered in the process of developing baseline scenarios from historic data. These include the following:
The number of stations that provide the required data quality, coverage and resolution are not distributed in a way that allows complete representation of the Kordofan states.
The selected baseline period (1961-1990) contains the warm, dry years of the Sahelian drought of the 1980s. This may drive average temperature values upward and average precipitation values downward within the baseline scenario. This in turn could bias the results by masking the significance of projected changes in temperature and precipitation. (See climate scenario section 1 for graphs illustrating precipitation and temperature trends during the 1961-1990 period.)
The 1950-1980 period - potentially a better representation of baseline climate - could not be used due to incomplete data sets and to the fact that the climate change scenario generator used in the assessment (MAGIC/SCENGEN) does not allow for the use of any baseline other than the 1961-1990 period.

1.2 Climate change scenario

Two distinct approaches have been applied to the development of climate change scenarios. Approach One utilizes General Circulation Models (HADCM2, BMRC, and GFDL) in conjunction with climate scenario generating software (Magicc/Scengen v. 2.4). Approach Two 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.

1.2.1 Approach One

The sections below outline the tools used in this approach.

MAGICC: The Model for Assessment of Greenhouse-gas Induced Climate Change (MAGICC) is a set of linked simple models that, collectively, fall in the genre of a Simple Climate Model as defined by Harvey *et al.* (1997). MAGICC is not a GCM but it utilizes a series of reduced-form models to emulate the behavior of fully three-dimensional, dynamic GCMs. MAGICC calculates the annual-mean global surface air temperature and global-mean sea-level implication of emissions scenarios for greenhouse gases and sulfur dioxide (Raper *et al*., 1996). Users are able to choose which emissions scenarios to use, or to define their own, and also can alter a number of model parameters to explore uncertainty. The model has been widely used by the IPCC in various assessments.[1] MAGICC has been developed in the Climatic Research Unit of the University of East Anglia.

SCENGEN: SCENGEN - a global and regional SCENario GENerator - is not a climate model; rather it is a simple database that contains the results of a large number of GCM experiments, as well as an observed global and four regional climate data sets. These various data fields are manipulated by SCENGEN, using the information about the rate and magnitude of global warming supplied by MAGICC and directed by the user's choice of important climate scenario characteristics. Together, MAGICC/SCENGEN converts scenarios of greenhouse gases and sulfur dioxide emissions of global-mean surface air temperature and sea-level change and then into descriptions of future changes in average regional climate.

SCENGEN has been developed over a number of years by the Climatic Research Unit, with Professor Tom Wigley and Dr. Mike Hulme leading development efforts. The latest version, 2.4, has an updated set of GCM patterns available and has a function for combining GHG and aerosol patterns of change. This version also contains observed 1961-1990 global climate data fields at 5º resolution (from the New et al. (1999) climate data set). SCENGEN has not been officially used by the IPCC but nearly all of the data sets used by SCENGEN - GCMs and observations - have been used or assessed in different IPCC assessments, including the third Assessment Report.

General Circulation Models: The IPCC Task Group on Scenarios for Climate Impacts Assessments defined a set of criteria that have been applied to identify General Circulation Models (GCMs) experiments whose results could be deposited in the IPCC DDC, experiments which could therefore form the basis for impact assessments undertaken from 1998, onward. These criteria included:
An IS92a-type forcing scenario;
Historically-forced integrations;
Integrations with/without aerosol forcing; up to 2100 for greenhouse gases only;
Integrations with results available now and with data logged in the public domain; and

- Documented models.

General circulation models are considered state-of-the-art tools for understanding the Earth's present climate and for estimating the effects on past and future climate of various natural and human factors. The selected models in this study are used for projection of mean temperature and precipitation in the context of climate change. The following models (HADCM2, BMRC, and GFDL) are use because:
HADCM2 has been used in regional scales.
BMRC uses parameters that the others do not (e.g., fluxes are adjusted in GFDL, while in BMRC they are not).
GFDL has been used in regional scales.

Emissions Scenario: Emission scenarios (IS92 a-f) were prepared for the 1992 IPCC Supplementary Report (IPCC 1992). The six scenarios report a range in emissions estimates based on different assumptions of GNP, population growth rate, energy use, land use and other socioeconomic actors that determine emission levels. These use a forcing scenario of 1% per

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[1] MAGICC (version 2.3) has been used extensively by the IPCC in its Second Assessment Report.

annum increase in equivalent greenhouse gas concentrations. Of the IPCC IS92 emissions scenarios, the 1% per annum increase in CO2 equivalent concentration is best approximated by the IS92a emissions scenario (according to IPCC (1996) calculations). This scenario is used in this study and is incorporated in the MAGICC software.

Resulting Scenarios: To generate climate change scenarios, the following settings were used by MAGICC/ SCENGEN:
Climate Sensitivity: Mid;
MAGICC default emissions scenario: IS92a;
Intervals: 2030 and 2060; and
Variable: Annual change in Temperature or Precipitation from baseline (19961-1990); monthly data generated.

The emissions of scenario IS92a were converted to atmospheric concentrations by MAGICC's gas model, and the concentrations are converted into radiative forcing potential for each gas. The net radiative forcing is then computed and input into a simple upwelling diffusion energy-balance climate model. The model produces global estimates of mean annual temperature.

For this assessment, the above tools were operated in conjunction to produce projections of monthly temperature and precipitation *change* for the years 2030 and 2060, for each GCM. As the results produced by MAGICC/SCENGEN are on a 5 by 5 degree grid, a linear interpolation process was applied to the results in order to derive station specific values. The monthly station-specific increments were then added to the baseline scenario monthly values for temperature and precipitation for each station. The result is a series of climate change scenarios – one for each GCM – each of which present temperature and precipitation values for milestone years 2030 and 2060, for each climate station.

Limitations:
A major disadvantage of using GCMs is that, although they may accurately represent global climate, their simulations of current regional climate are often inaccurate (Houghton et al., 1996) and may significantly underestimate or overestimate current regional temperature and precipitation. Even a combination of several GCMs may not represent the full range of potential climate changes in a region.
GCMs estimate uniform climate changes in grid boxes several hundred kilometers across. Thus, short distances between the five Kordofan stations could not be captured in the interpolation equations.
The MAGICC/SCENGEN software does not produce output on geographic and temporal scales fine enough for impact assessment, making linear interpolation necessary.
The only baseline available in MAGICC/SCENGEN software is 1961-1990.
Inter-annual climate variability is not internalized in the MAGICC/SCENGEN software.

According to the resulting scenarios, projected monthly mean temperature, relative to the historic baseline (1961-1990), shows a general rising trend in the five stations in both milestone years 2030 and 2060. The rise in 2060 is higher than in 2030. As the tables provided at the end of this section indicate, the results from the three GCM models show a change in temperature between 0.1° and 3.4°C.

The general trend in projected monthly precipitation relative to the historic baseline shows an increase. In general terms, the HADCM2 model shows a modest rise in the five stations. The BMRC model reports a slight rise in rainfall, except in Rashad, Kadugli and Babanusa where from July through September (the heart of the growing season for many food crops) a decline was reported in both 2030 and 2060. Precipitation values generated with the GFDL model remain close to the baseline

1.2.2 Approach Two

The second approach relies on a series of assumptions to create incremental, or “synthetic”, scenarios. This approach was applied only to the agroforestry assessment.

The scenarios are based on increments of change in mean temperature and precipitation away from some baseline. The increments for mean temperature are 1.5˚, 2.5˚, 3.5˚, and 4.5˚ C and for precipitation are 10%, 20%, 0%, -10%, and -20%. From the historic baseline (1961-1990) a systematic increment was applied to both mean monthly temperature (e.g., +1.5 C) and precipitation (e.g., +20%). Using expert judgment to determine expected variations in mean temperature and precipitation, roughly 20 climate change scenarios were developed. These scenarios were then used to calculate predicted impacts on the exposure units in the agroforestry assessment.

Figure 1.2: Annual rainfall in Sudan

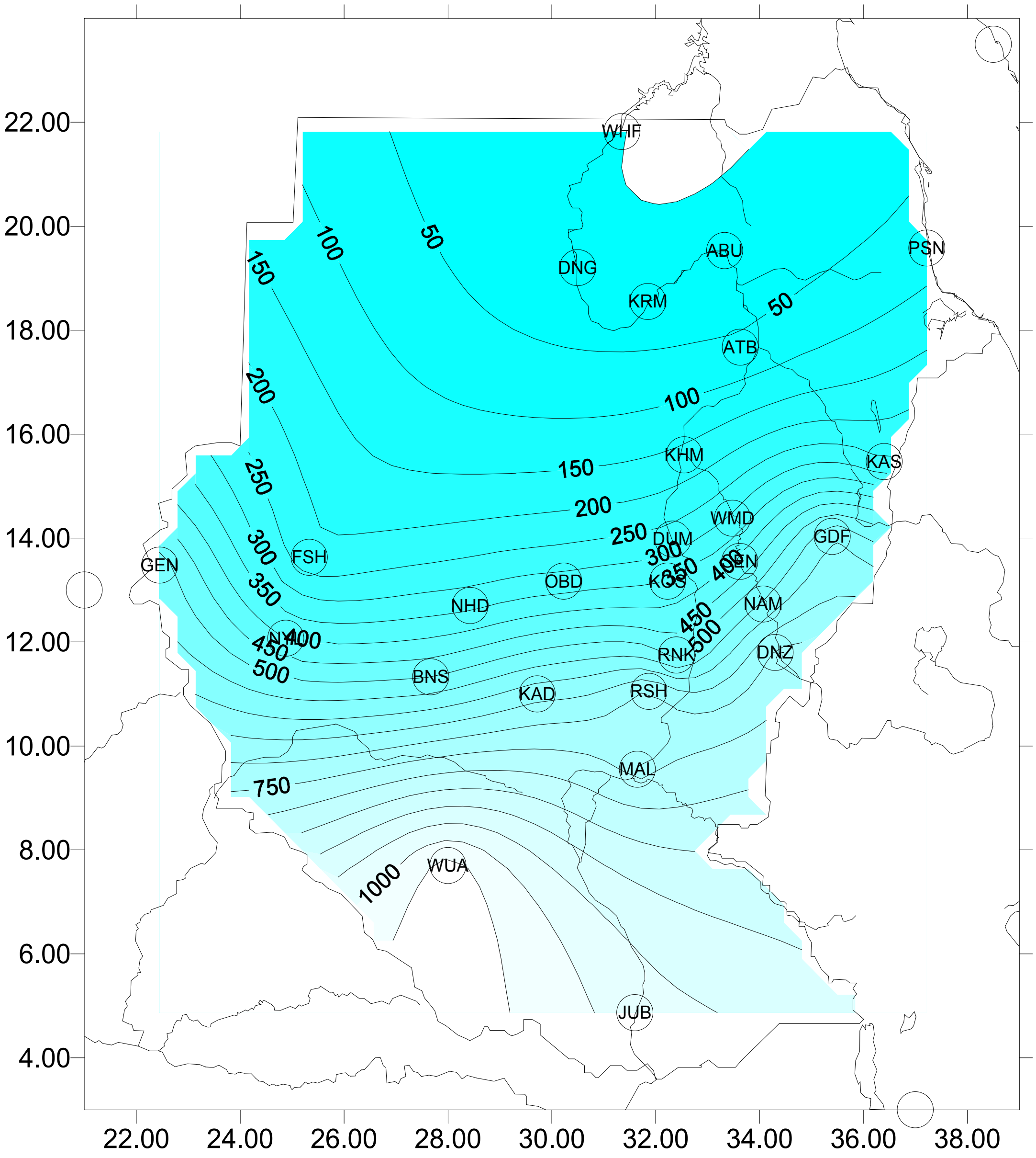


Figure 1.3: Mean maximum temperature for the Sudan

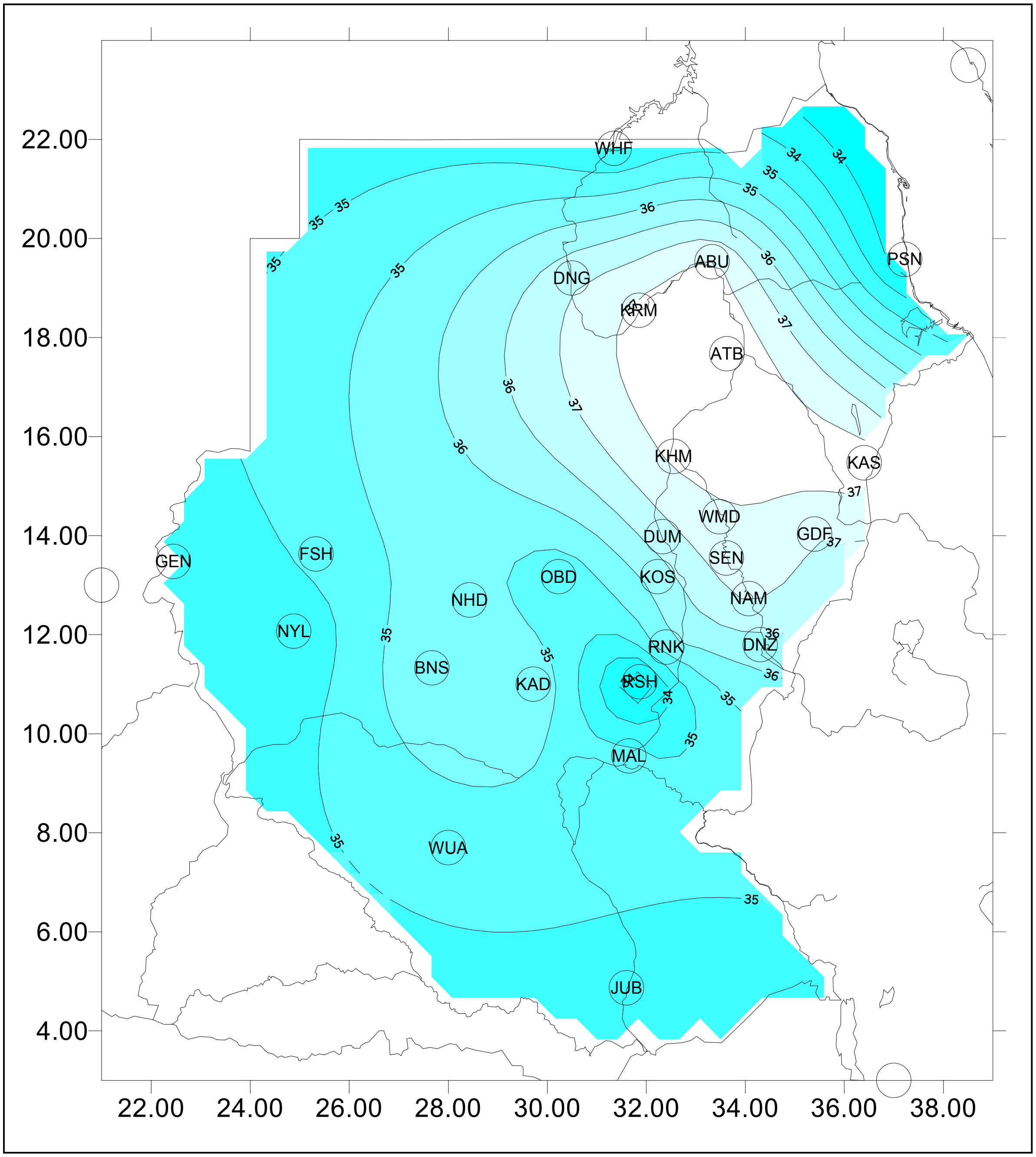
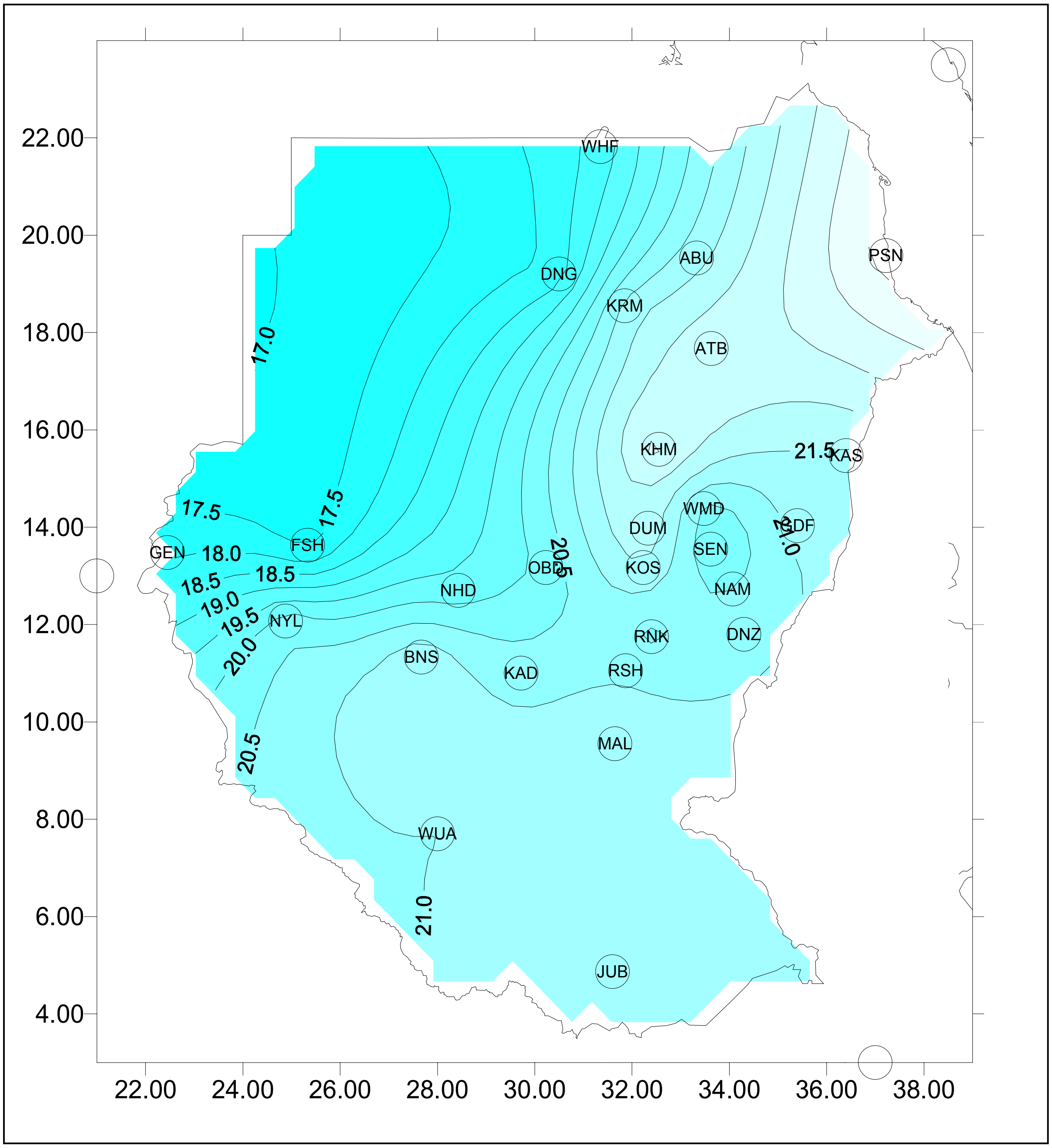


Figure 1.4: Mean minimum temperature for the Sudan



The above rainfall and temperature charts illustrate the large variations that exist in the country. These ranges were very important in the calculation of predicted impacts on the exposure units in the agroforestry assessment.

Table 1.2: Baseline and Climate Change-Induced Temperature In 2030 In Kordofan (HADCM2 Model)

		Temperature (degrees C)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	21.7	23.8	27.4	30.3	32.0	31.0	28.5	27.5	28.3	29.4	25.9	22.3
	Projected	22.9	25.1	28.8	31.8	33.5	32.5	30.1	29.2	29.9	30.9	27.3	23.5
	Average Increase	1.2	1.3	1.4	1.5	1.5	1.5	1.6	1.7	1.6	1.5	1.4	1.2
En Nahud	Average (1961-1990)	22.1	24.3	27.7	30.4	31.7	30.7	28.4	27.7	28.6	29.2	25.9	22.7
	Projected	23.2	25.5	29.1	31.9	33.2	32.2	30.0	29.4	30.3	30.8	27.3	23.9
	Average Increase	1.1	1.2	1.4	1.5	1.5	1.5	1.6	1.7	1.7	1.6	1.4	1.2
Rashad	Average (1961-1990)	24.6	26.1	28.5	30.3	29.6	27.3	25.3	25.1	25.5	26.9	26.9	25.3
	Projected	25.2	26.7	29.2	31.0	30.3	28.0	26.1	25.9	26.3	27.7	27.6	26.0
	Average Increase	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.7	0.7
Kadugli	Average (1961-1990)	25.9	27.7	30.5	31.7	31.7	28.8	26.9	26.3	26.7	27.7	27.5	26.4
	Projected	26.8	28.6	31.4	32.7	32.7	29.8	28.0	27.4	27.8	28.8	28.5	27.3
	Average Increase	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.0	0.9
Babanusa	Average (1961-1990)	24.2	27.1	30.3	32.3	32.5	27.9	27.8	27.5	28.1	29.5	28.2	26.1
	Projected	25.2	28.2	31.4	33.5	33.7	29.1	29.2	28.9	29.5	30.8	29.4	27.2
	Average Increase	1.0	1.1	1.1	1.2	1.2	1.2	1.4	1.4	1.4	1.3	1.2	1.1

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Table 1.3: Baseline and Climate Change-Induced Precipitation In 2030 In Kordofan (HADCM2 Model)

		Precipitation (mm per month)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	0.0	0.0	0.4	1.4	8.4	22.5	98.2	110.6	61.7	14.5	0.3	0.0
	Projected	0.0	0.0	0.4	1.3	8.0	22.5	98.6	111.0	64.1	16.4	0.3	0.0
	Average Increase	0.0	0.0	0.0	-0.1	-0.4	0.0	0.4	0.4	2.4	1.9	0.0	0.0
En Nahud	Average (1961-1990)	0.0	0.0	0.5	1.7	10.1	45.7	105.0	115.3	44.3	13.3	0.0	0.0
	Projected	0.0	0.0	0.5	1.6	9.6	45.6	105.5	115.8	46.1	15.2	0.0	0.0
	Average Increase	0.0	0.0	0.0	-0.1	-0.5	-0.1	0.5	0.5	1.8	1.9	0.0	0.0
Rashad	Average (1961-1990)	0.0	0.1	1.8	9.1	47.5	103.6	154.4	173.7	145.8	80.2	1.2	0.3
	Projected	0.0	0.1	1.8	9.2	47.8	101.6	152.9	173.6	143.9	80.4	1.3	0.3
	Average Increase	0.0	0.0	0.0	0.1	0.3	-2.0	-1.5	-0.1	-1.9	0.2	0.1	0.0
Kadugli	Average (1961-1990)	0.0	0.0	3.3	10.9	60.6	99.7	134.9	163.1	98.7	61.0	0.9	0.0
	Projected	0.0	0.0	3.4	11.1	61.1	97.0	133.0	162.8	96.9	61.3	1.0	0.0
	Average Increase	0.0	0.0	0.1	0.2	0.5	-2.7	-1.9	-0.3	-1.8	0.3	0.1	0.0
Babanusa	Average (1961-1990)	0.0	0.0	0.9	6.2	21.7	88.0	125.2	125.3	107.0	22.9	0.1	0.0
	Projected	0.0	0.0	0.9	6.4	22.0	84.6	122.1	124.1	103.7	22.7	0.1	0.0
	Average Increase	0.0	0.0	0.0	0.2	0.3	-3.4	-3.1	-1.2	-3.3	-0.2	0.0	0.0

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Table 1.4: Baseline and Climate Change-Induced Temperature In 2060 In Kordofan (HADCM2 Model)

		Temperature (degrees C)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	21.7	23.8	27.4	30.3	32.0	31.0	28.5	27.5	28.3	29.4	25.9	22.3
	Projected	23.8	26.1	29.8	32.9	34.7	33.7	31.4	30.5	31.2	32.2	28.3	24.5
	Average Increase	2.1	2.3	2.4	2.6	2.7	2.7	2.9	3.0	2.9	2.8	2.4	2.2
En Nahud	Average (1961-1990)	22.1	24.3	27.7	30.4	31.7	30.7	28.4	27.7	28.6	29.2	25.9	22.7
	Projected	24.2	26.5	30.2	33.0	34.5	33.4	31.3	30.8	31.6	32.0	28.3	24.9
	Average Increase	2.1	2.2	2.5	2.6	2.8	2.7	2.9	3.1	3.0	2.8	2.4	2.2
Rashad	Average (1961-1990)	24.6	26.1	28.5	30.3	29.6	27.3	25.3	25.1	25.5	26.9	26.9	25.3
	Projected	25.8	27.2	29.7	31.6	30.8	28.6	26.7	26.5	26.9	28.3	28.2	26.5
	Average Increase	1.2	1.1	1.2	1.3	1.2	1.3	1.4	1.4	1.4	1.4	1.3	1.2
Kadugli	Average (1961-1990)	25.9	27.7	30.5	31.7	31.7	28.8	26.9	26.3	26.7	27.7	27.5	26.4
	Projected	27.5	29.3	32.2	33.5	33.4	30.6	28.9	28.3	28.7	29.7	29.3	28.0
	Average Increase	1.6	1.6	1.7	1.8	1.7	1.8	2.0	2.0	2.0	2.0	1.8	1.6
Babanusa	Average (1961-1990)	24.2	27.1	30.3	32.3	32.5	27.9	27.8	27.5	28.1	29.5	28.2	26.1
	Projected	26.1	28.9	32.2	34.4	34.5	30.1	30.2	29.9	30.5	31.9	30.3	28.0
	Average Increase	1.9	1.8	1.9	2.1	2.0	2.2	2.4	2.4	2.4	2.4	2.1	1.9

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Table 1.5: Baseline and Climate Change-Induced Precipitation In 2060 In Kordofan (HADCM2 Model)

		Precipitation (mm per month)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	0.0	0.0	0.4	1.4	8.4	22.5	98.2	110.6	61.7	14.5	0.3	0.0
	Projected	0.0	0.0	0.4	1.3	7.8	22.5	98.9	111.3	66.1	17.9	0.4	0.0
	Average Increase	0.0	0.0	0.0	-0.1	-0.6	0.0	0.7	0.7	4.4	3.4	0.1	0.0
En Nahud	Average (1961-1990)	0.0	0.0	0.5	1.7	10.1	45.7	105.0	115.3	44.3	13.3	0.0	0.0
	Projected	0.0	0.0	0.5	1.5	9.1	45.5	105.9	116.2	47.5	16.7	0.0	0.0
	Average Increase	0.0	0.0	0.0	-0.2	-1.0	-0.2	0.9	0.9	3.2	3.4	0.0	0.0
Rashad	Average (1961-1990)	0.0	0.1	1.8	9.1	47.5	103.6	154.4	173.7	145.8	80.2	1.2	0.3
	Projected	0.0	0.1	1.9	9.3	48.0	100.1	151.7	173.5	142.4	80.6	1.4	0.4
	Average Increase	0.0	0.0	0.1	0.2	0.5	-3.5	-2.7	-0.2	-3.4	0.4	0.2	0.1
Kadugli	Average (1961-1990)	0.0	0.0	3.3	10.9	60.6	99.7	134.9	163.1	98.7	61.0	0.9	0.0
	Projected	0.0	0.0	3.5	11.3	61.5	94.9	131.6	162.6	95.4	61.5	1.1	0.0
	Average Increase	0.0	0.0	0.2	0.4	0.9	-4.8	-3.3	-0.5	-3.3	0.5	0.2	0.0
Babanusa	Average (1961-1990)	0.0	0.0	0.9	6.2	21.7	88.0	125.2	125.3	107.0	22.9	0.1	0.0
	Projected	0.0	0.0	1.0	6.6	22.2	81.9	119.7	123.2	101.0	22.6	0.1	0.0
	Average Increase	0.0	0.0	0.1	0.4	0.5	-6.1	-5.5	-2.1	-6.0	-0.3	0.0	0.0

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Table 1.6: Baseline and Climate Change-Induced Temperature In 2030 In Kordofan (BMRC Model)

		Temperature (degrees C)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	21.7	23.8	27.4	30.3	32.0	31.0	28.5	27.5	28.3	29.4	25.9	22.3
	Projected	22.2	24.6	28.0	30.8	32.6	31.7	29.1	27.7	28.4	29.7	26.4	23.1
	Average Increase	0.5	0.8	0.6	0.5	0.6	0.7	0.6	0.2	0.1	0.3	0.5	0.8
En Nahud	Average (1961-1990)	22.1	24.3	27.7	30.4	31.7	30.7	28.4	27.7	28.6	29.2	25.9	22.7
	Projected	22.5	25.0	28.2	30.9	32.3	31.5	29.0	27.9	28.7	29.5	26.5	23.6
	Average Increase	0.4	0.7	0.5	0.5	0.6	0.8	0.6	0.2	0.1	0.3	0.6	0.9
Rashad	Average (1961-1990)	24.6	26.1	28.5	30.3	29.6	27.3	25.3	25.1	25.5	26.9	26.9	25.3
	Projected	24.8	26.5	28.7	30.5	29.8	27.7	25.7	25.4	25.7	27.1	27.1	25.6
	Average Increase	0.2	0.4	0.2	0.2	0.2	0.4	0.4	0.3	0.2	0.2	0.2	0.3
Kadugli	Average (1961-1990)	25.9	27.7	30.5	31.7	31.7	28.8	26.9	26.3	26.7	27.7	27.5	26.4
	Projected	26.2	28.2	30.8	32.0	32.0	29.3	27.5	26.8	27.0	27.9	27.8	26.8
	Average Increase	0.3	0.5	0.3	0.3	0.3	0.5	0.6	0.5	0.3	0.2	0.3	0.4
Babanusa	Average (1961-1990)	24.2	27.1	30.3	32.3	32.5	27.9	27.8	27.5	28.1	29.5	28.2	26.1
	Projected	24.6	27.8	30.6	32.6	32.9	28.5	28.4	28.0	28.5	29.8	28.5	26.5
	Average Increase	0.4	0.7	0.3	0.3	0.4	0.6	0.6	0.5	0.4	0.3	0.3	0.4

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Table 1.7: Baseline and Climate Change-Induced Precipitation In 2030 In Kordofan (BMRC Model)

		Precipitation (mm per month)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	0.0	0.0	0.4	1.4	8.4	22.5	98.2	110.6	61.7	14.5	0.3	0.0
	Projected	0.0	0.0	0.4	1.5	8.6	22.6	104.5	119.4	68.1	15.8	0.4	0.0
	Average Increase	0.0	0.0	0.0	0.1	0.2	0.1	6.3	8.8	6.4	1.3	0.1	0.0
En Nahud	Average (1961-1990)	0.0	0.0	0.5	1.7	10.1	45.7	105.0	115.3	44.3	13.3	0.0	0.0
	Projected	0.0	0.0	0.5	1.8	10.4	45.1	112.9	126.5	50.4	14.2	0.0	0.0
	Average Increase	0.0	0.0	0.0	0.1	0.3	-0.6	7.9	11.2	6.1	0.9	0.0	0.0
Rashad	Average (1961-1990)	0.0	0.1	1.8	9.1	47.5	103.6	154.4	173.7	145.8	80.2	1.2	0.3
	Projected	0.0	0.1	1.8	9.1	47.4	103.0	151.0	167.3	143.7	85.6	1.3	0.3
	Average Increase	0.0	0.0	0.0	0.0	-0.1	-0.6	-3.4	-6.4	-2.1	5.4	0.1	0.0
Kadugli	Average (1961-1990)	0.0	0.0	3.3	10.9	60.6	99.7	134.9	163.1	98.7	61.0	0.9	0.0
	Projected	0.0	0.0	3.4	10.9	60.4	99.0	130.6	154.3	96.7	66.7	1.0	0.0
	Average Increase	0.0	0.0	0.1	0.0	-0.2	-0.7	-4.3	-8.8	-2.0	5.7	0.1	0.0
Babanusa	Average (1961-1990)	0.0	0.0	0.9	6.2	21.7	88.0	125.2	125.3	107.0	22.9	0.1	0.0
	Projected	0.0	0.0	0.9	6.1	21.6	87.9	119.7	115.3	102.8	25.4	0.1	0.0
	Average Increase	0.0	0.0	0.0	-0.1	-0.1	-0.1	-5.5	-10.0	-4.2	2.5	0.0	0.0

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Table 1.8: Baseline and Climate Change-Induced Temperature In 2060 In Kordofan (BMRC Model)

		Temperature (degrees C)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	21.7	23.8	27.4	30.3	32.0	31.0	28.5	27.5	28.3	29.4	25.9	22.3
	Projected	22.6	25.2	28.4	31.2	33.0	32.3	29.4	27.9	28.5	29.9	26.9	23.7
	Average Increase	0.9	1.4	1.0	0.9	1.0	1.3	0.9	0.4	0.2	0.5	1.0	1.4
En Nahud	Average (1961-1990)	22.1	24.3	27.7	30.4	31.7	30.7	28.4	27.7	28.6	29.2	25.9	22.7
	Projected	23.0	25.7	28.7	31.3	32.8	32.1	29.4	28.1	28.7	29.7	27.0	24.1
	Average Increase	0.9	1.4	1.0	0.9	1.1	1.4	1.0	0.4	0.1	0.5	1.1	1.4
Rashad	Average (1961-1990)	24.6	26.1	28.5	30.3	29.6	27.3	25.3	25.1	25.5	26.9	26.9	25.3
	Projected	25.0	26.8	28.9	30.7	30.0	28.0	26.1	25.6	26.0	27.2	27.2	25.8
	Average Increase	0.4	0.7	0.4	0.4	0.4	0.7	0.8	0.5	0.5	0.3	0.3	0.5
Kadugli	Average (1961-1990)	25.9	27.7	30.5	31.7	31.7	28.8	26.9	26.3	26.7	27.7	27.5	26.4
	Projected	26.5	28.6	31.1	32.3	32.3	29.7	27.9	27.1	27.3	28.2	27.9	27.1
	Average Increase	0.6	0.9	0.6	0.6	0.6	0.9	1.0	0.8	0.6	0.5	0.4	0.7
Babanusa	Average (1961-1990)	24.2	27.1	30.3	32.3	32.5	27.9	27.8	27.5	28.1	29.5	28.2	26.1
	Projected	24.9	28.3	30.9	33.0	33.2	28.9	28.8	28.4	28.9	30.1	28.7	26.9
	Average Increase	0.7	1.2	0.6	0.7	0.7	1.0	1.0	0.9	0.8	0.6	0.5	0.8

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Table 1.9: Baseline and Climate Change-Induced Precipitation In 2060 In Kordofan (BMRC Model)

		Precipitation (mm per month)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	0.0	0.0	0.4	1.4	8.4	22.5	98.2	110.6	61.7	14.5	0.3	0.0
	Projected	0.0	0.0	0.4	1.5	8.7	22.6	109.5	126.3	73.1	16.8	0.4	0.0
	Average Increase	0.0	0.0	0.0	0.1	0.3	0.1	11.3	15.7	11.4	2.3	0.1	0.0
En Nahud	Average (1961-1990)	0.0	0.0	0.5	1.7	10.1	45.7	105.0	115.3	44.3	13.3	0.0	0.0
	Projected	0.0	0.0	0.6	1.8	10.6	44.7	119.3	135.3	55.2	14.9	0.0	0.0
	Average Increase	0.0	0.0	0.1	0.1	0.5	-1.0	14.3	20.0	10.9	1.6	0.0	0.0
Rashad	Average (1961-1990)	0.0	0.1	1.8	9.1	47.5	103.6	154.4	173.7	145.8	80.2	1.2	0.3
	Projected	0.0	0.1	1.9	9.1	47.2	102.5	148.2	162.2	142.0	89.8	1.4	0.3
	Average Increase	0.0	0.0	0.1	0.0	-0.3	-1.1	-6.2	-11.5	-3.8	9.6	0.2	0.0
Kadugli	Average (1961-1990)	0.0	0.0	3.3	10.9	60.6	99.7	134.9	163.1	98.7	61.0	0.9	0.0
	Projected	0.0	0.0	3.5	10.8	60.2	98.3	127.3	147.5	95.1	71.1	1.1	0.0
	Average Increase	0.0	0.0	0.2	-0.1	-0.4	-1.4	-7.6	-15.6	-3.6	10.1	0.2	0.0
Babanusa	Average (1961-1990)	0.0	0.0	0.9	6.2	21.7	88.0	125.2	125.3	107.0	22.9	0.1	0.0
	Projected	0.0	0.0	1.0	6.1	21.5	87.8	115.3	107.5	99.5	27.4	0.1	0.0
	Average Increase	0.0	0.0	0.1	-0.1	-0.2	-0.2	-9.9	-17.8	-7.5	4.5	0.0	0.0

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Table 1.10: Baseline ad Climate Change-Induced Temperature In 2030 In Kordofan (GFDL Model)

		Temperature (degrees C)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	21.7	23.8	27.4	30.3	32.0	31.0	28.5	27.5	28.3	29.4	25.9	22.3
	Projected	22.7	24.7	28.1	31.2	32.8	32.0	29.5	28.2	29.2	30.6	26.4	22.9
	Average Increase	1.0	0.9	0.7	0.9	0.8	1.0	1.0	0.7	0.9	1.2	0.5	0.6
En Nahud	Average (1961-1990)	22.1	24.3	27.7	30.4	31.7	30.7	28.4	27.7	28.6	29.2	25.9	22.7
	Projected	23.1	25.2	28.5	31.3	32.4	31.7	29.5	28.4	29.5	30.4	26.3	23.3
	Average Increase	1.0	0.9	0.8	0.9	0.7	1.0	1.1	0.7	0.9	1.2	0.4	0.6
Rashad	Average (1961-1990)	24.6	26.1	28.5	30.3	29.6	27.3	25.3	25.1	25.5	26.9	26.9	25.3
	Projected	25.0	26.5	28.8	30.7	30.0	27.7	25.8	25.4	25.9	27.4	27.3	25.7
	Average Increase	0.4	0.4	0.3	0.4	0.4	0.4	0.5	0.3	0.4	0.5	0.4	0.4
Kadugli	Average (1961-1990)	25.9	27.7	30.5	31.7	31.7	28.8	26.9	26.3	26.7	27.7	27.5	26.4
	Projected	26.5	28.2	30.9	32.2	32.2	29.3	27.6	26.8	27.2	28.5	28.0	26.9
	Average Increase	0.6	0.5	0.4	0.5	0.5	0.5	0.7	0.5	0.5	0.8	0.5	0.5
Babanusa	Average (1961-1990)	24.2	27.1	30.3	32.3	32.5	27.9	27.8	27.5	28.1	29.5	28.2	26.1
	Projected	24.9	27.7	30.7	32.9	33.1	28.5	28.6	28.1	28.7	30.4	28.9	26.7
	Average Increase	0.7	0.6	0.4	0.6	0.6	0.6	0.8	0.6	0.6	0.9	0.7	0.6

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Table 1.11: Baseline and Climate Change-Induced Precipitation In 2030 In Kordofan (GFDL Model)

		Precipitation (mm per month)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	0.0	0.0	0.4	1.4	8.4	22.5	98.2	110.6	61.7	14.5	0.3	0.0
	Projected	0.0	0.0	0.4	1.5	8.4	21.8	94.5	121.9	56.2	17.7	0.3	0.0
	Average Increase	0.0	0.0	0.0	0.1	0.0	-0.7	-3.7	11.3	-5.5	3.2	0.0	0.0
En Nahud	Average (1961-1990)	0.0	0.0	0.5	1.7	10.1	45.7	105.0	115.3	44.3	13.3	0.0	0.0
	Projected	0.0	0.0	0.5	1.8	10.0	44.4	98.9	128.1	40.7	16.5	0.0	0.0
	Average Increase	0.0	0.0	0.0	0.1	-0.1	-1.3	-6.1	12.8	-3.6	3.2	0.0	0.0
Rashad	Average (1961-1990)	0.0	0.1	1.8	9.1	47.5	103.6	154.4	173.7	145.8	80.2	1.2	0.3
	Projected	0.0	0.1	1.9	9.0	47.9	102.4	153.8	177.9	145.4	83.6	1.3	0.3
	Average Increase	0.0	0.0	0.1	-0.1	0.4	-1.2	-0.6	4.2	-0.4	3.4	0.1	0.0
Kadugli	Average (1961-1990)	0.0	0.0	3.3	10.9	60.6	99.7	134.9	163.1	98.7	61.0	0.9	0.0
	Projected	0.0	0.0	3.6	10.8	61.3	98.1	134.2	168.6	98.3	64.6	1.0	0.0
	Average Increase	0.0	0.0	0.3	-0.1	0.7	-1.6	-0.7	5.5	-0.4	3.6	0.1	0.0
Babanusa	Average (1961-1990)	0.0	0.0	0.9	6.2	21.7	88.0	125.2	125.3	107.0	22.9	0.1	0.0
	Projected	0.0	0.0	1.0	6.0	21.7	86.3	125.3	128.7	106.8	24.2	0.1	0.0
	Average Increase	0.0	0.0	0.1	-0.2	0.0	-1.7	0.1	3.4	-0.2	1.3	0.0	0.0

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Table 1.12: Baseline and Climate Change-Induced Temperature In 2060 In Kordofan (GFDL Model)

		Temperature (degrees C)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	21.7	23.8	27.4	30.3	32.0	31.0	28.5	27.5	28.3	29.4	25.9	22.3
	Projected	23.6	25.7	28.9	32.0	33.4	32.8	30.5	28.8	30.0	31.5	26.6	23.2
	Average Increase	1.9	1.9	1.5	1.7	1.4	1.8	2.0	1.3	1.7	2.1	0.7	0.9
En Nahud	Average (1961-1990)	22.1	24.3	27.7	30.4	31.7	30.7	28.4	27.7	28.6	29.2	25.9	22.7
	Projected	24.0	26.5	29.6	32.2	32.9	32.3	30.5	29.0	30.2	31.4	26.5	23.5
	Average Increase	1.9	2.2	1.9	1.8	1.2	1.6	2.1	1.3	1.6	2.2	0.6	0.8
Rashad	Average (1961-1990)	24.6	26.1	28.5	30.3	29.6	27.3	25.3	25.1	25.5	26.9	26.9	25.3
	Projected	26.2	27.5	29.5	31.6	30.9	28.6	26.9	26.2	26.9	28.8	28.2	26.5
	Average Increase	1.6	1.4	1.0	1.3	1.3	1.3	1.6	1.1	1.4	1.9	1.3	1.2
Kadugli	Average (1961-1990)	25.9	27.7	30.5	31.7	31.7	28.8	26.9	26.3	26.7	27.7	27.5	26.4
	Projected	27.4	29.2	31.5	33.0	32.9	30.0	28.5	27.4	28.1	29.7	28.6	27.5
	Average Increase	1.5	1.5	1.0	1.3	1.2	1.2	1.6	1.1	1.4	2.0	1.1	1.1
Babanusa	Average (1961-1990)	24.2	27.1	30.3	32.3	32.5	27.9	27.8	27.5	28.1	29.5	28.2	26.1
	Projected	25.7	28.5	31.3	33.6	33.7	29.1	29.4	28.5	29.5	31.5	29.3	27.2
	Average Increase	1.5	1.4	1.0	1.3	1.2	1.2	1.6	1.0	1.4	2.0	1.1	1.1

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Table 1.13: Baseline and Climate Change-Induced Precipitation In 2060 In Kordofan (GFDL Model)

		Precipitation (mm per month)											
Station		**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
El Obeid	Average (1961-1990)	0.0	0.0	0.4	1.4	8.4	22.5	98.2	110.6	61.7	14.5	0.3	0.0
	Projected	0.0	0.0	0.4	1.5	8.3	21.3	91.5	130.8	51.9	20.2	0.4	0.0
	Average Increase	0.0	0.0	0.0	0.1	-0.1	-1.2	-6.7	20.2	-9.8	5.7	0.1	0.0
En Nahud	Average (1961-1990)	0.0	0.0	0.5	1.7	10.1	45.7	105.0	115.3	44.3	13.3	0.0	0.0
	Projected	0.0	0.0	0.5	1.9	9.9	43.4	94.1	138.2	37.8	19.0	0.0	0.0
	Average Increase	0.0	0.0	0.0	0.2	-0.2	-2.3	-10.9	22.9	-6.5	5.7	0.0	0.0
Rashad	Average (1961-1990)	0.0	0.1	1.8	9.1	47.5	103.6	154.4	173.7	145.8	80.2	1.2	0.3
	Projected	0.0	0.1	2.0	9.0	48.2	101.5	153.4	181.3	145.0	86.4	1.4	0.3
	Average Increase	0.0	0.0	0.2	-0.1	0.7	-2.1	-1.0	7.6	-0.8	6.2	0.2	0.0
Kadugli	Average (1961-1990)	0.0	0.0	3.3	10.9	60.6	99.7	134.9	163.1	98.7	61.0	0.9	0.0
	Projected	0.0	0.0	3.9	10.7	61.8	96.8	133.7	173.0	98.0	67.4	1.1	0.0
	Average Increase	0.0	0.0	0.6	-0.2	1.2	-2.9	-1.2	9.9	-0.7	6.4	0.2	0.0
Babanusa	Average (1961-1990)	0.0	0.0	0.9	6.2	21.7	88.0	125.2	125.3	107.0	22.9	0.1	0.0
	Projected	0.0	0.0	1.1	5.9	21.7	84.9	125.5	131.4	106.7	25.3	0.1	0.0
	Average Increase	0.0	0.0	0.2	-0.3	0.0	-3.1	0.3	6.1	-0.3	2.4	0.0	0.0

1. Source for average date for 1961-90 is Department of Meteorology
2. Source for climate change projections is MAGICC/SCENGEN outputs, IS92A scenario

Figure 1.5: Projected average monthly temperature difference at En Nahud in 2030 from selected GCMs

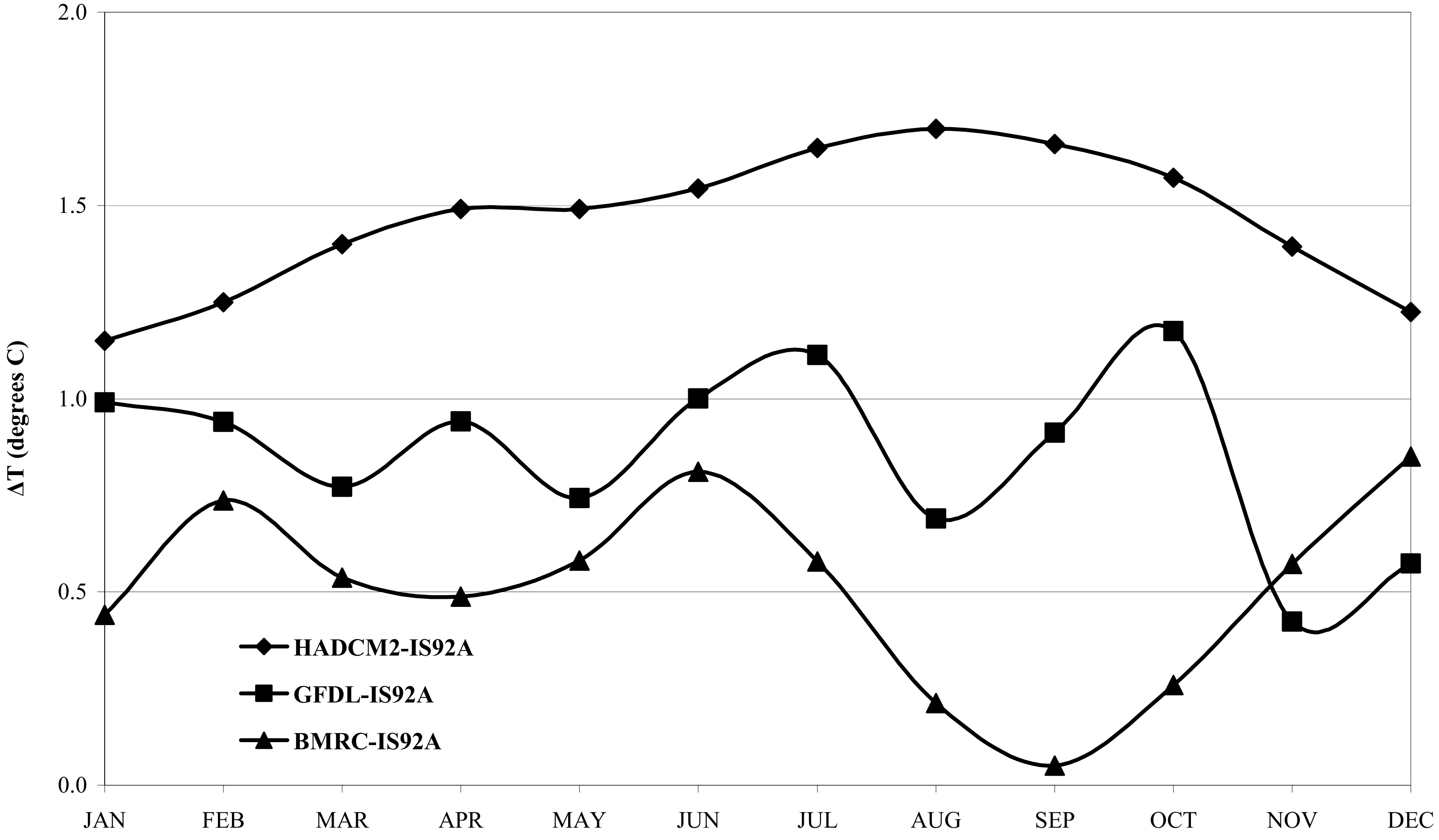


Figure 1.6: Projected average monthly temperature difference at Rashad in 2030 from selected GCMs

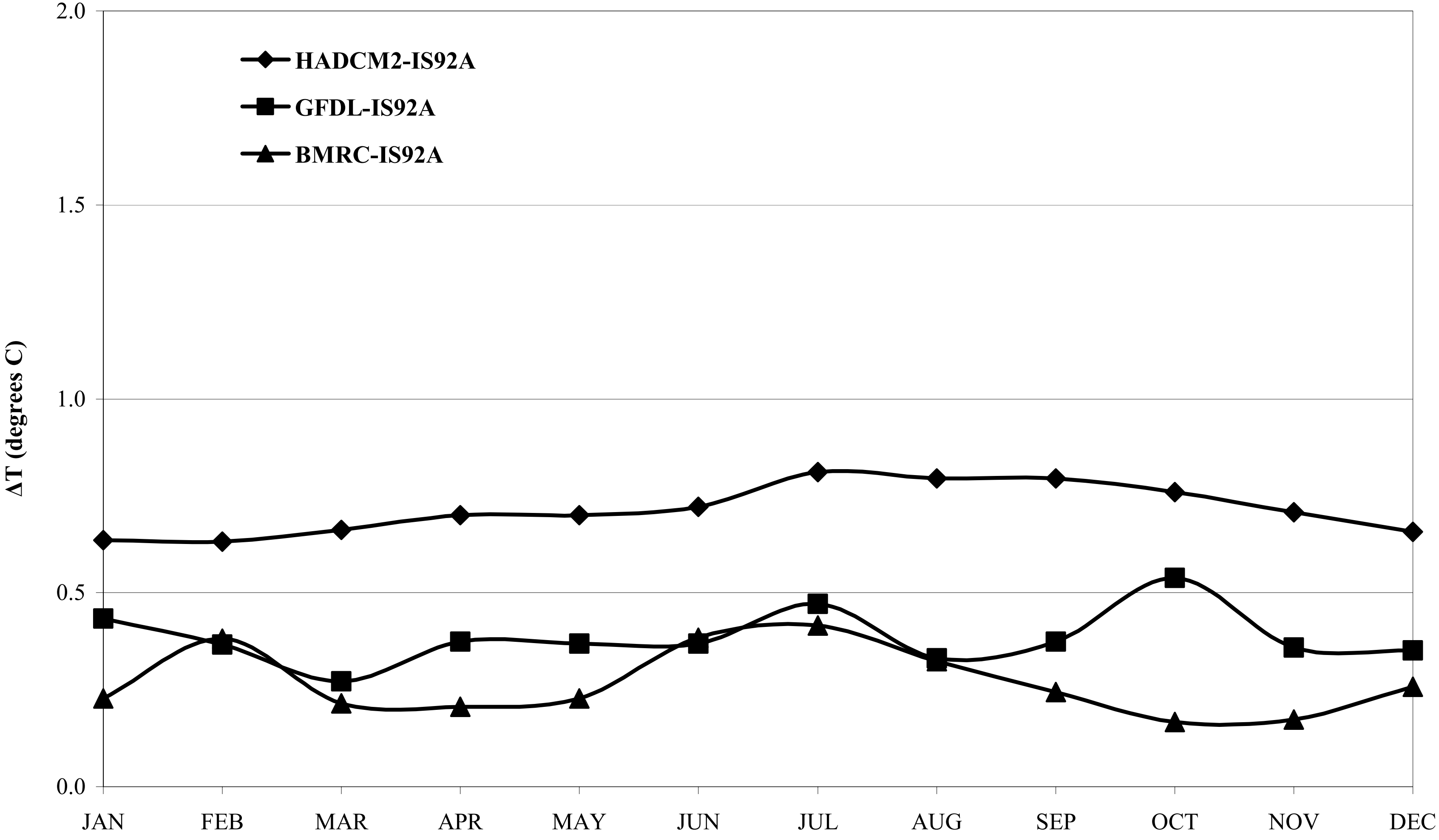


Figure 1.7: Projected average monthly temperature difference at Kadugli in 2030 from selected GCMs

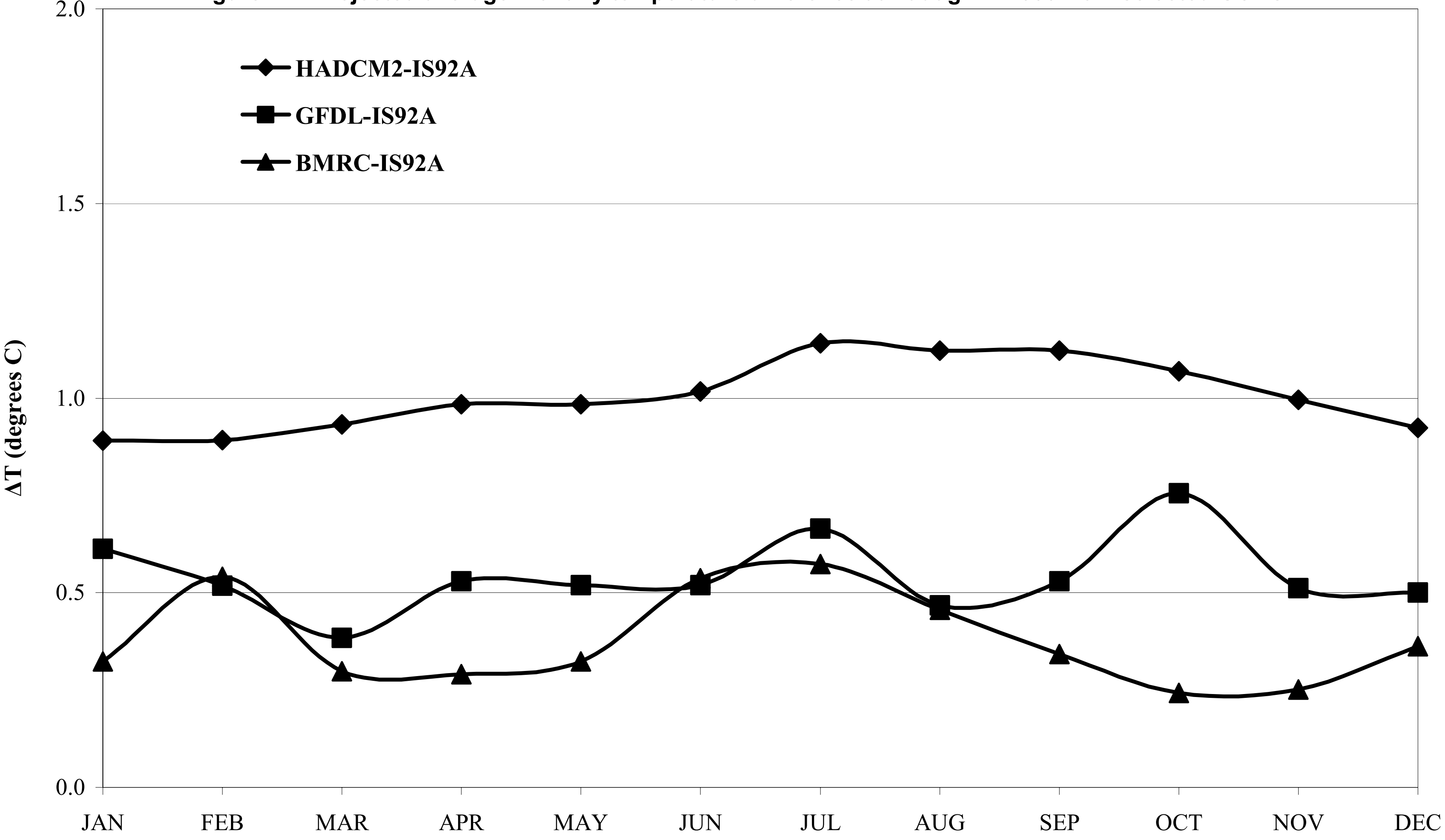


Figure 1.8: Projected average monthly temperature difference at Babanusa in 2030 from selected GCMs

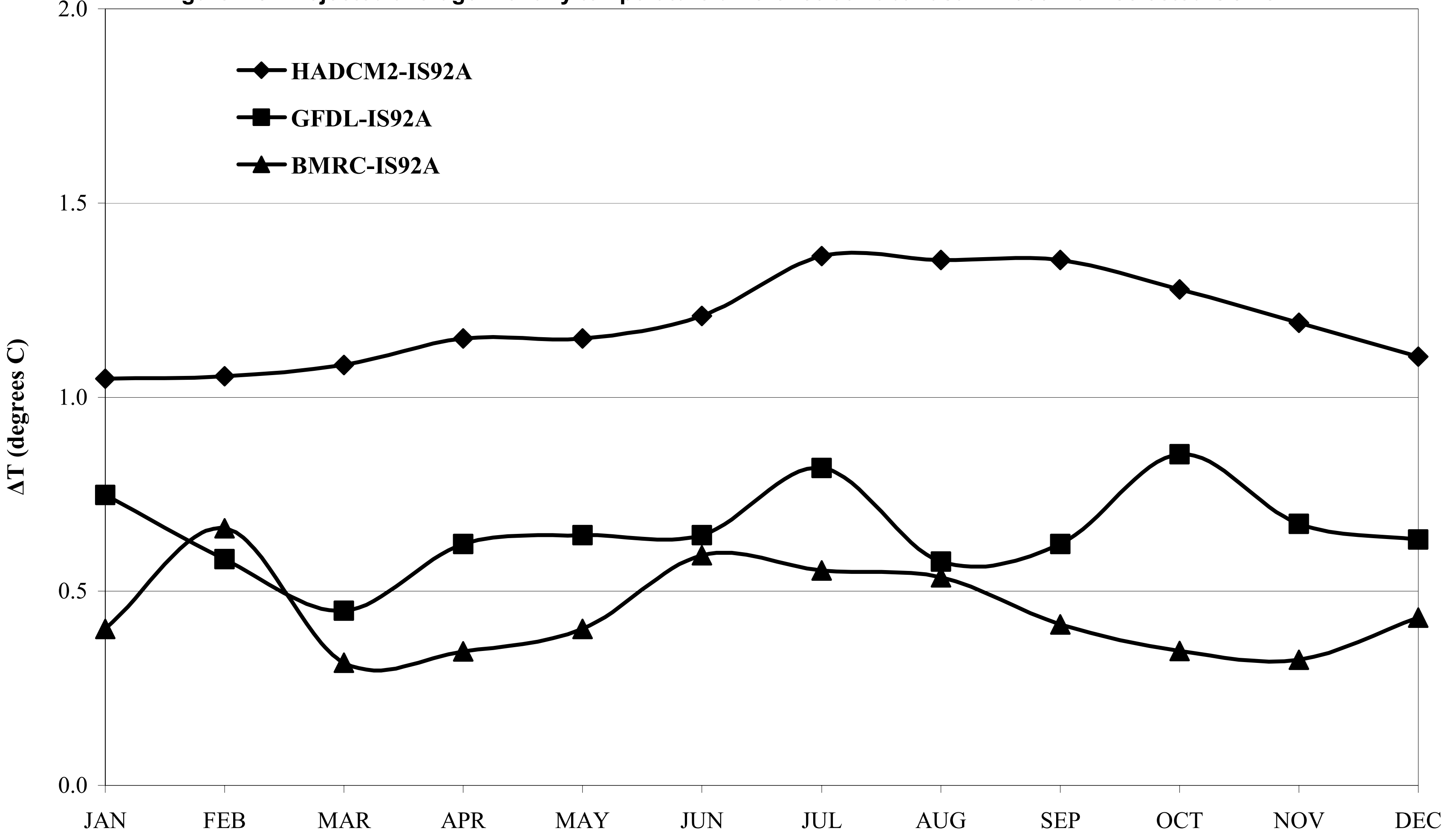


Figure 1.9: Projected average monthly temperature difference at El Obeid in 2060 from selected GCMs

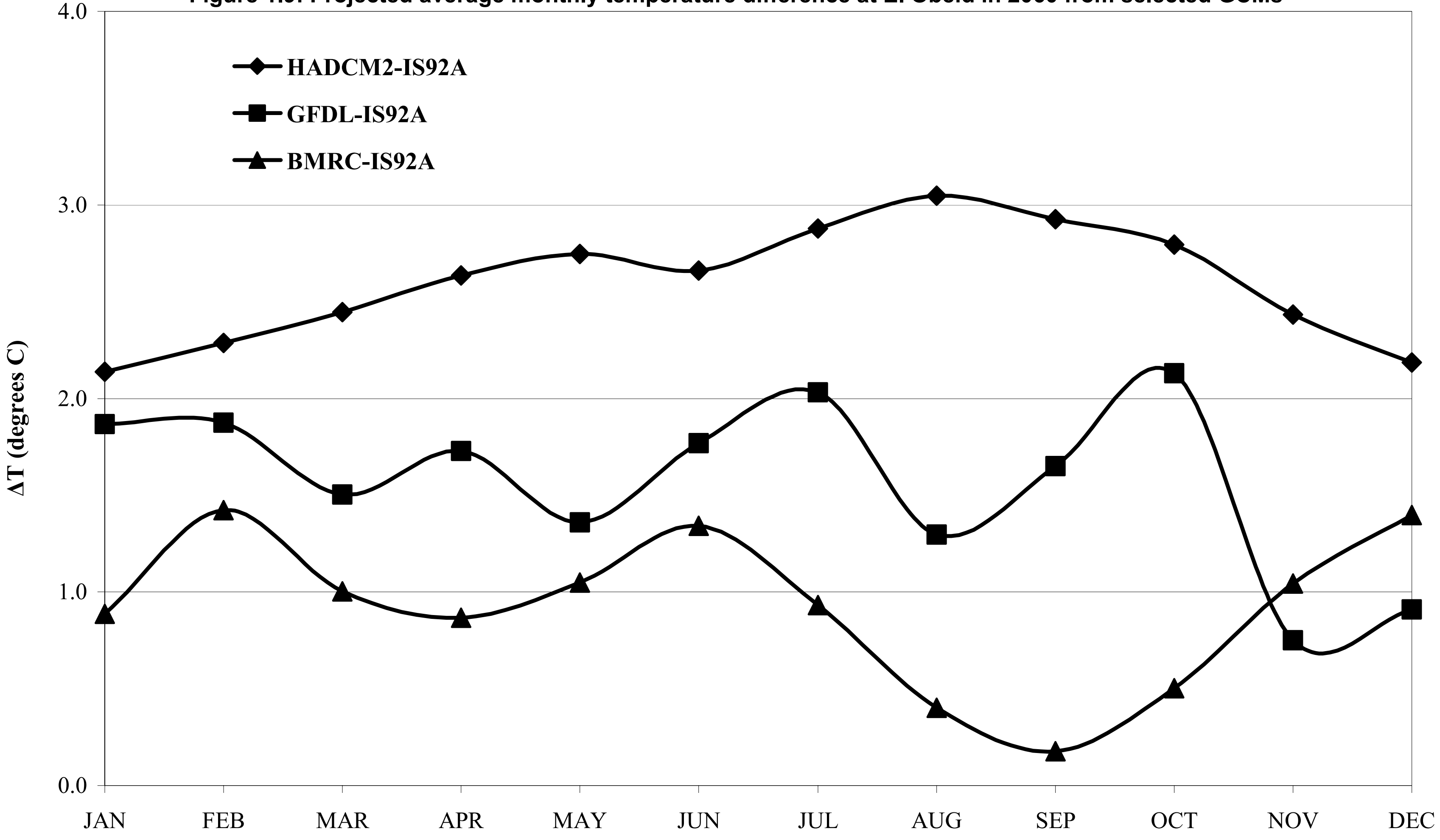


Figure 1.10: Projected average monthly temperature difference at En Nahud in 2060 from selected GCMs

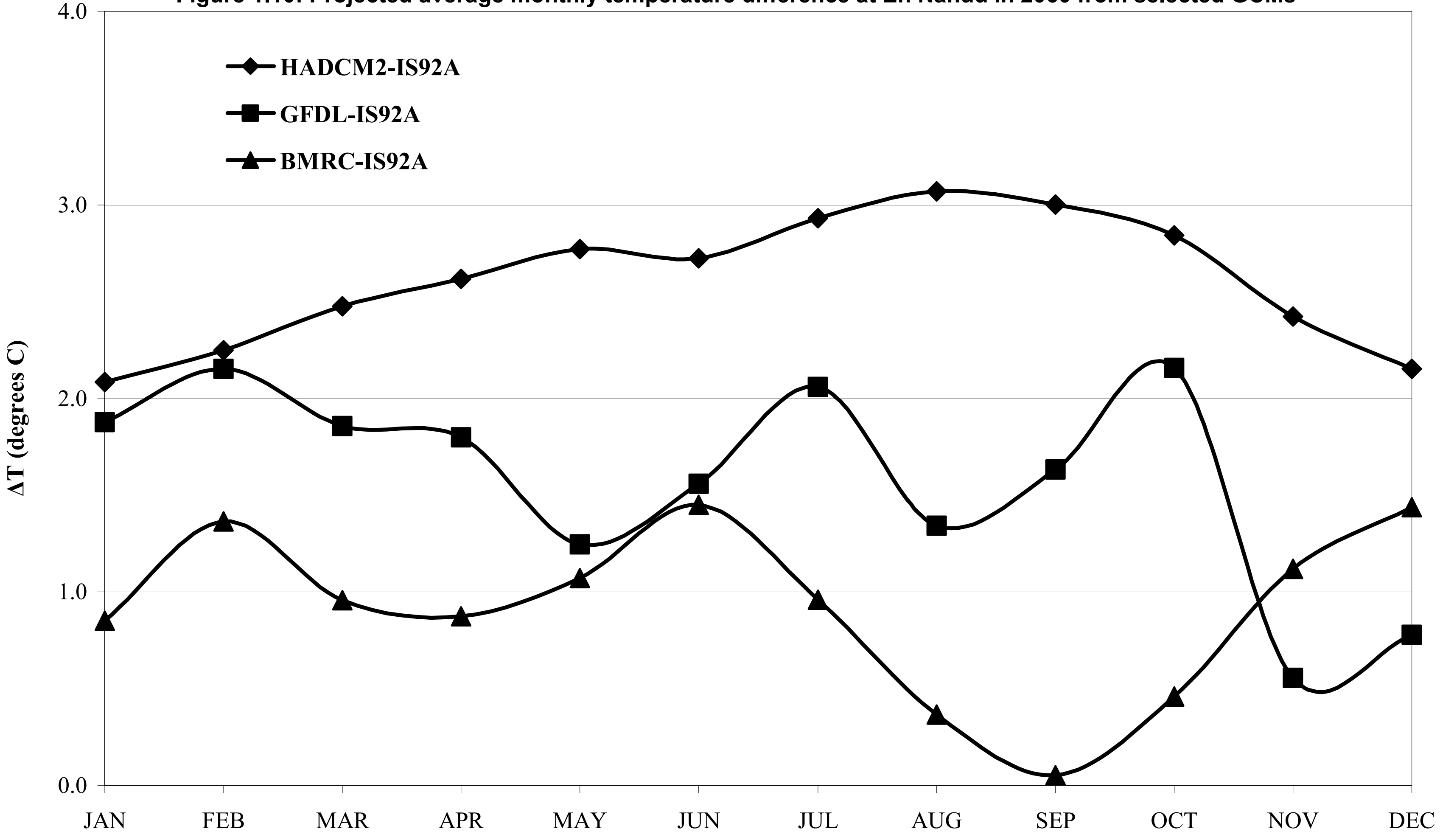


Figure 1.11: Projected average monthly temperature difference at Rashad in 2060 from selected GCMs

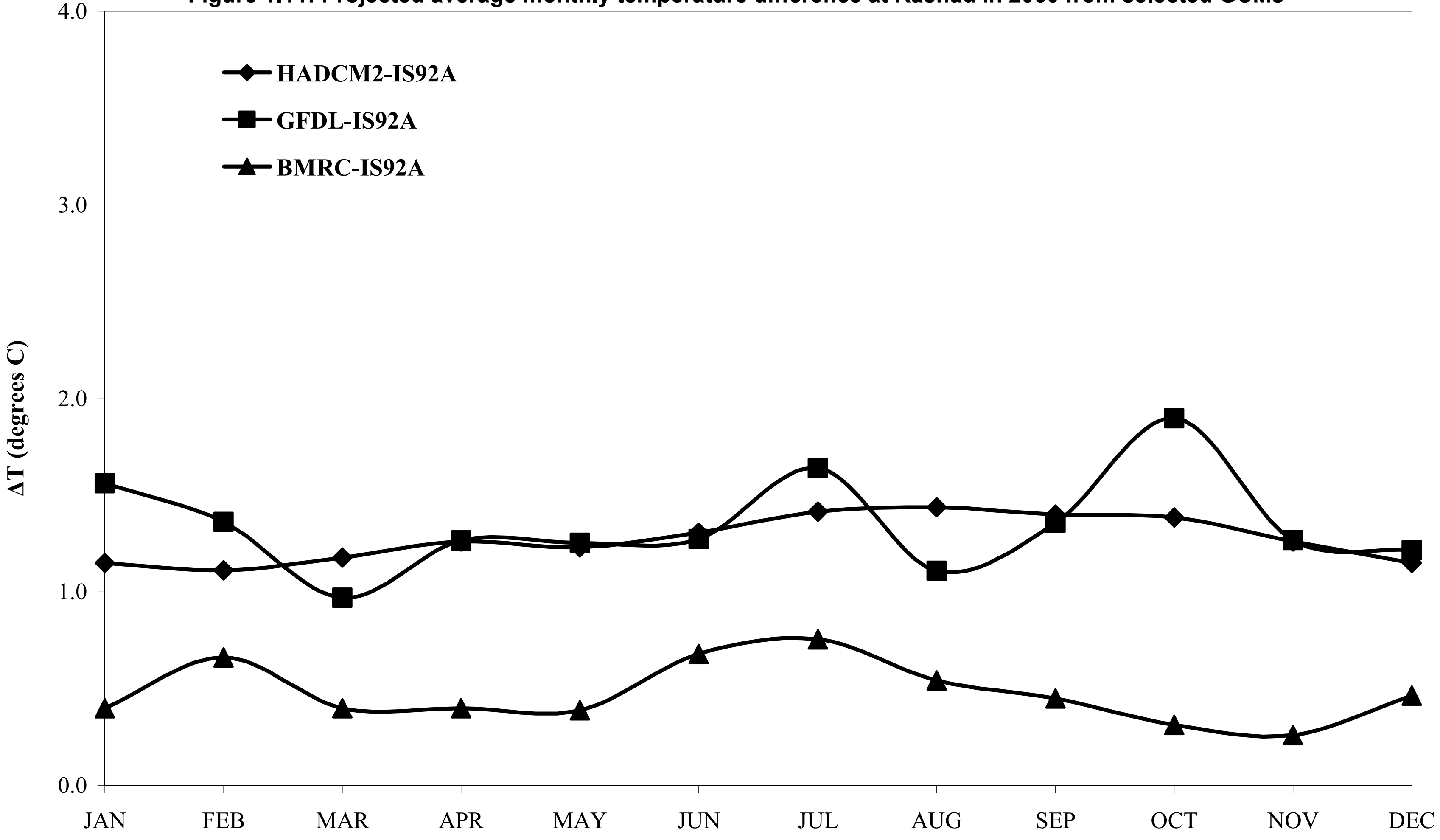


Figure 1.12: Projected average monthly temperature difference at Kadugli in 2060 from selected GCMs

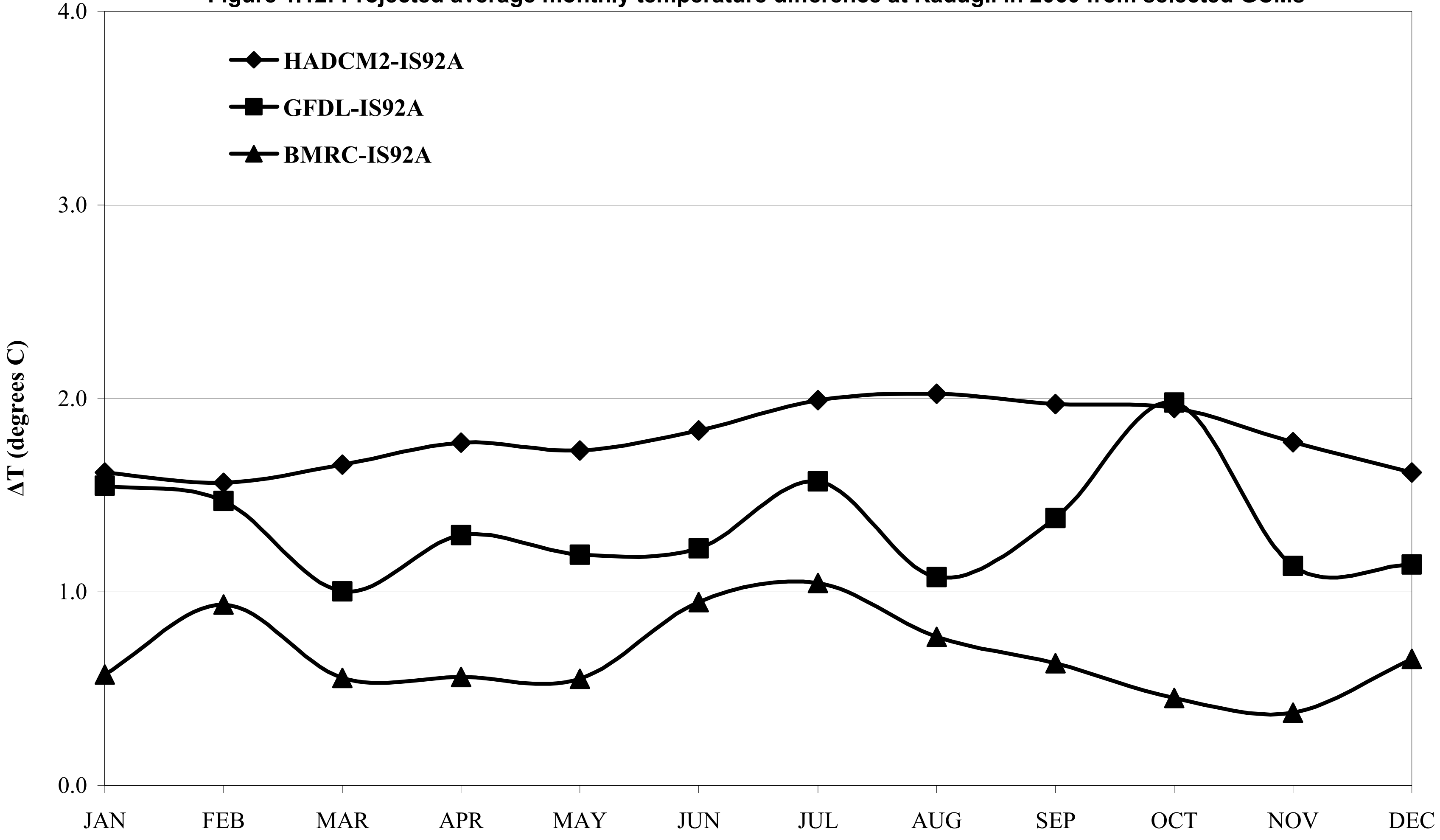


Figure 1.13: Projected average monthly temperature difference at Babanusa in 2060 from selected GCMs

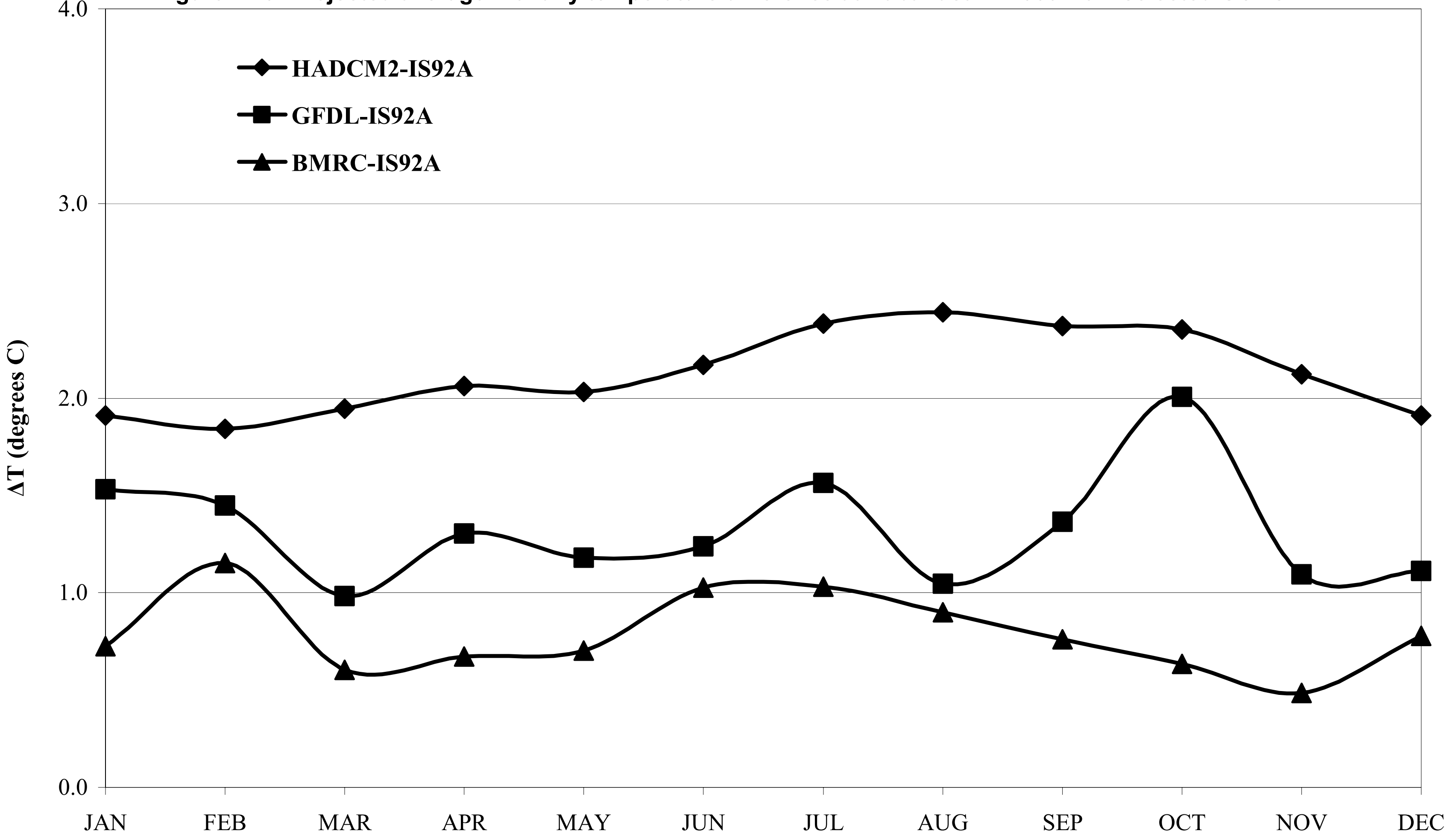


Figure 1.14: Projected average temperature differences at all stations in 2030 from the HADCM2 GCM

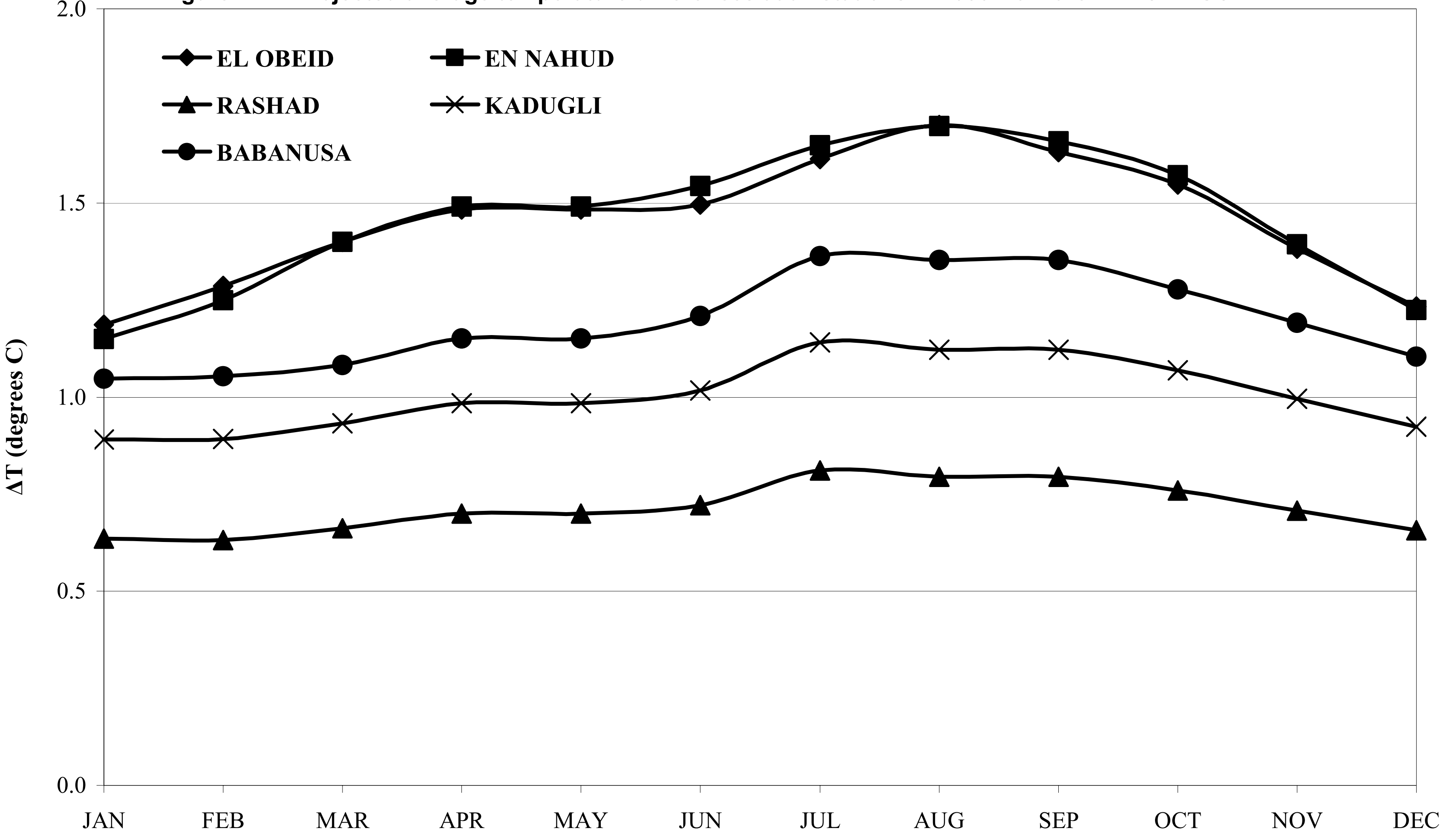


Figure 1.15: Projected average temperature differences at all stations in 2030 from the BMRC GCM

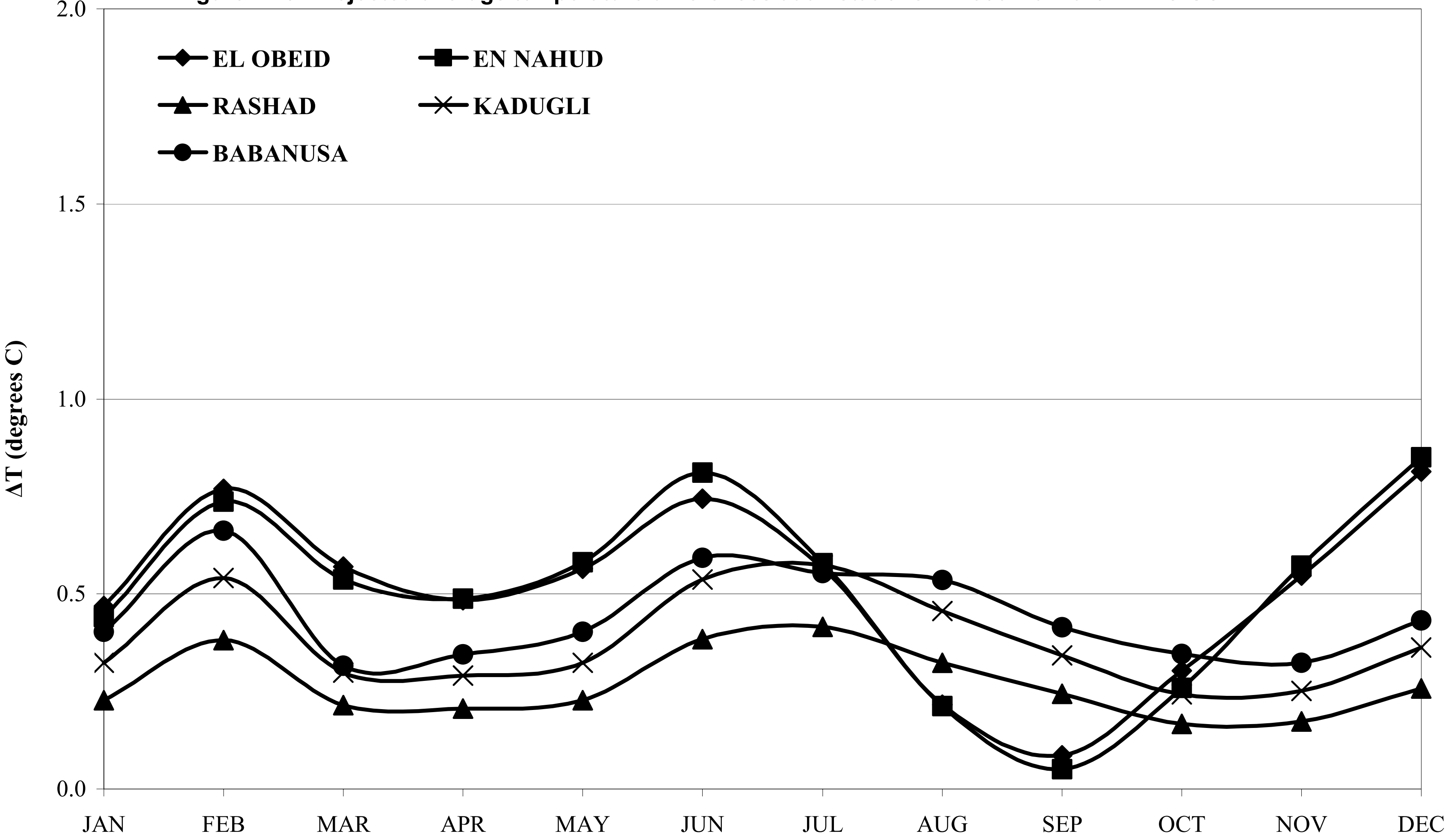


Figure 1.16: Projected average temperature differences at all stations in 2030 from the GFDL GCM

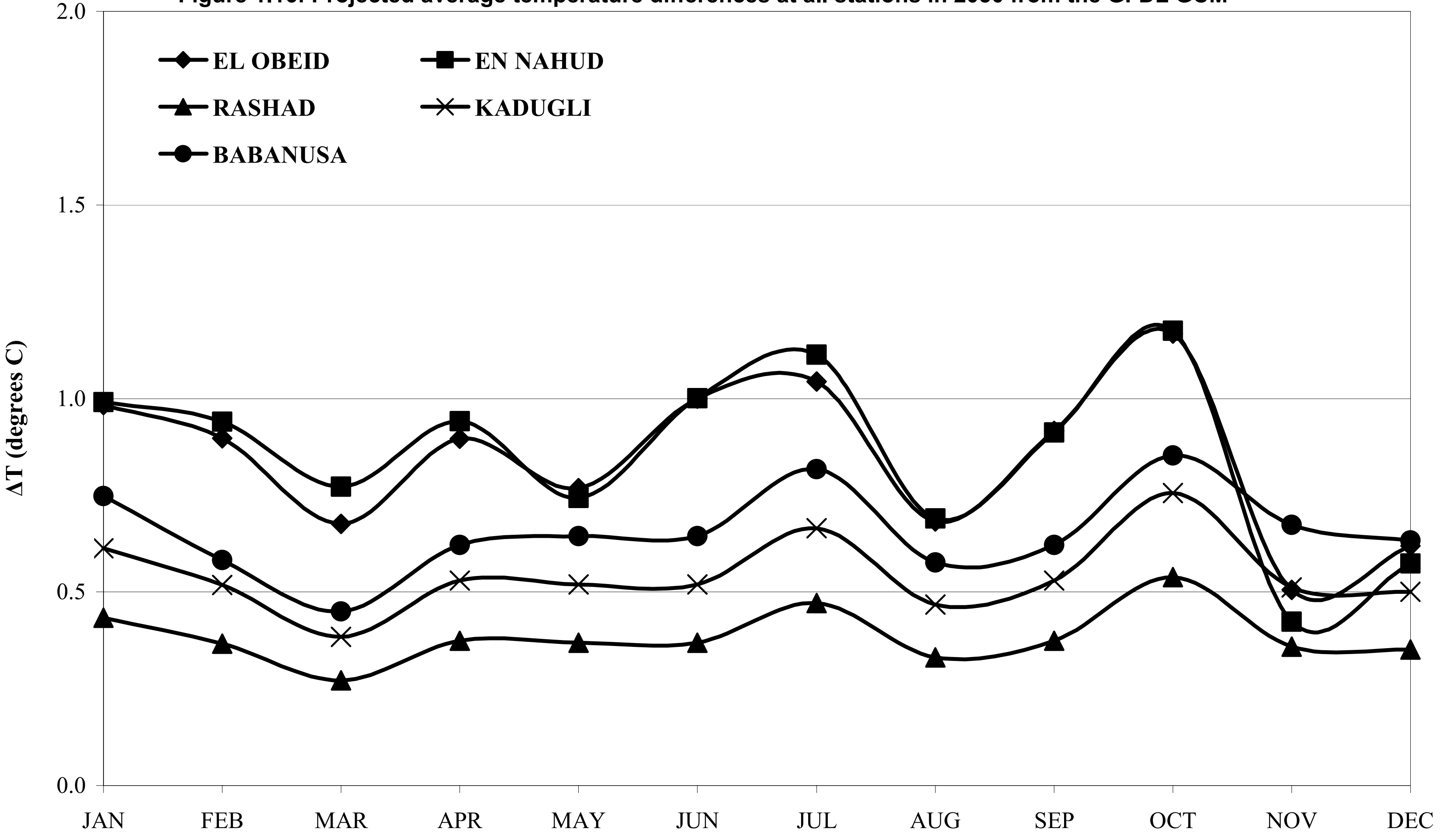


Figure 1.17: Projected average temperature differences at all stations in 2060 from the HADCM2 GCM

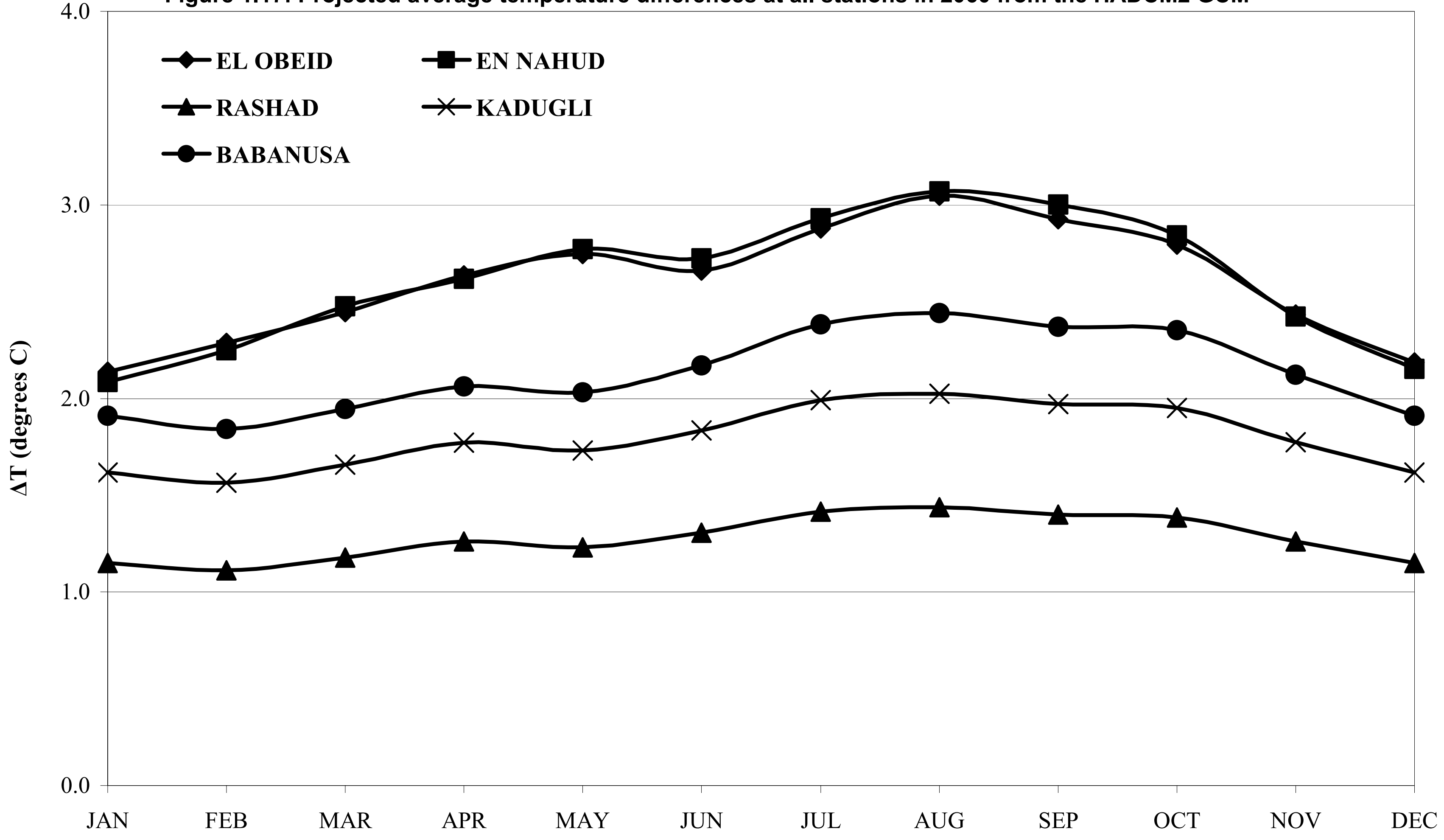


Figure 1.18: Projected average temperature differences at all stations in 2060 from the BMRC GCM

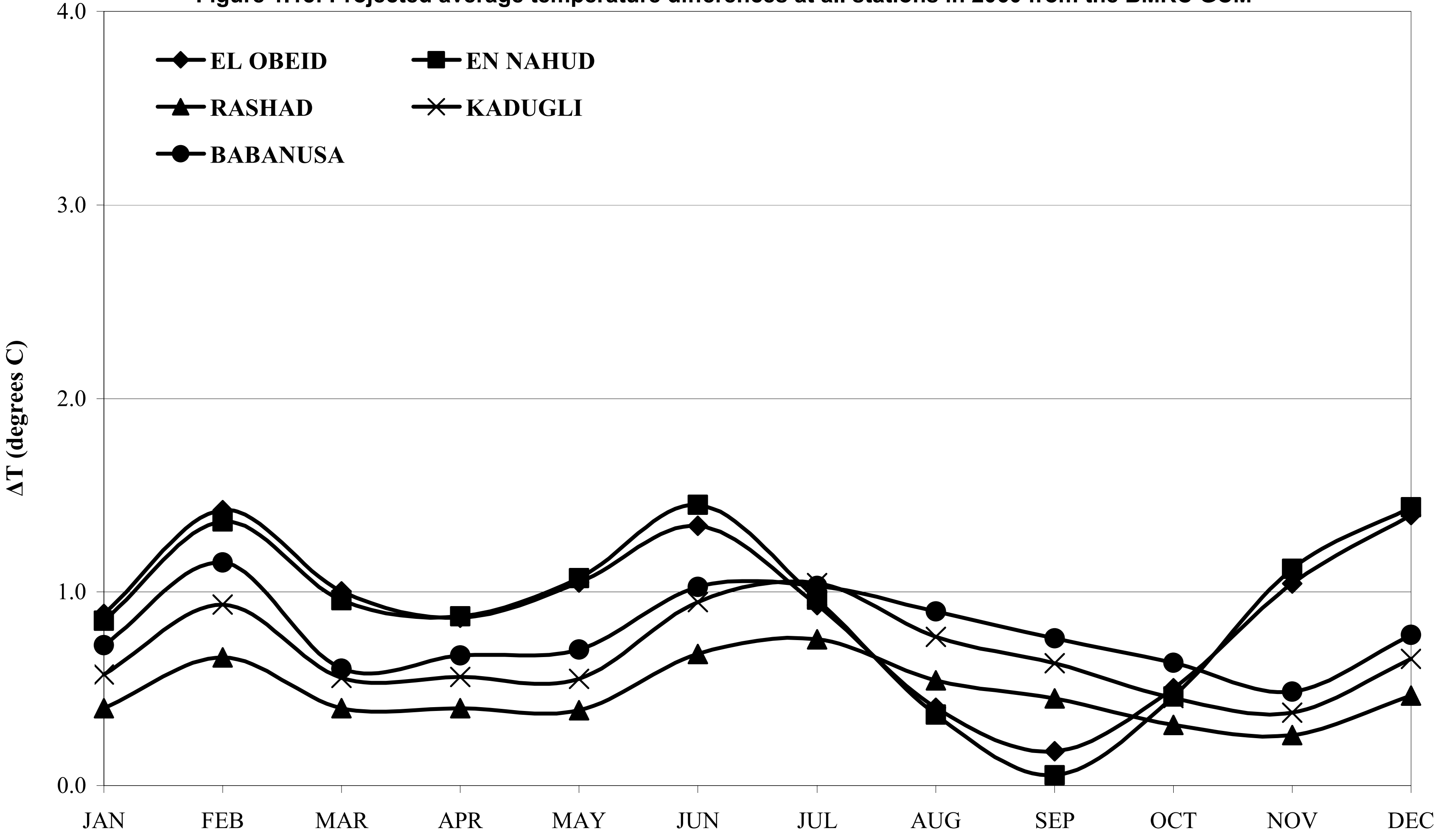


Figure 1.19: Projected average temperature differences at all stations in 2060 from the GFDL GCM

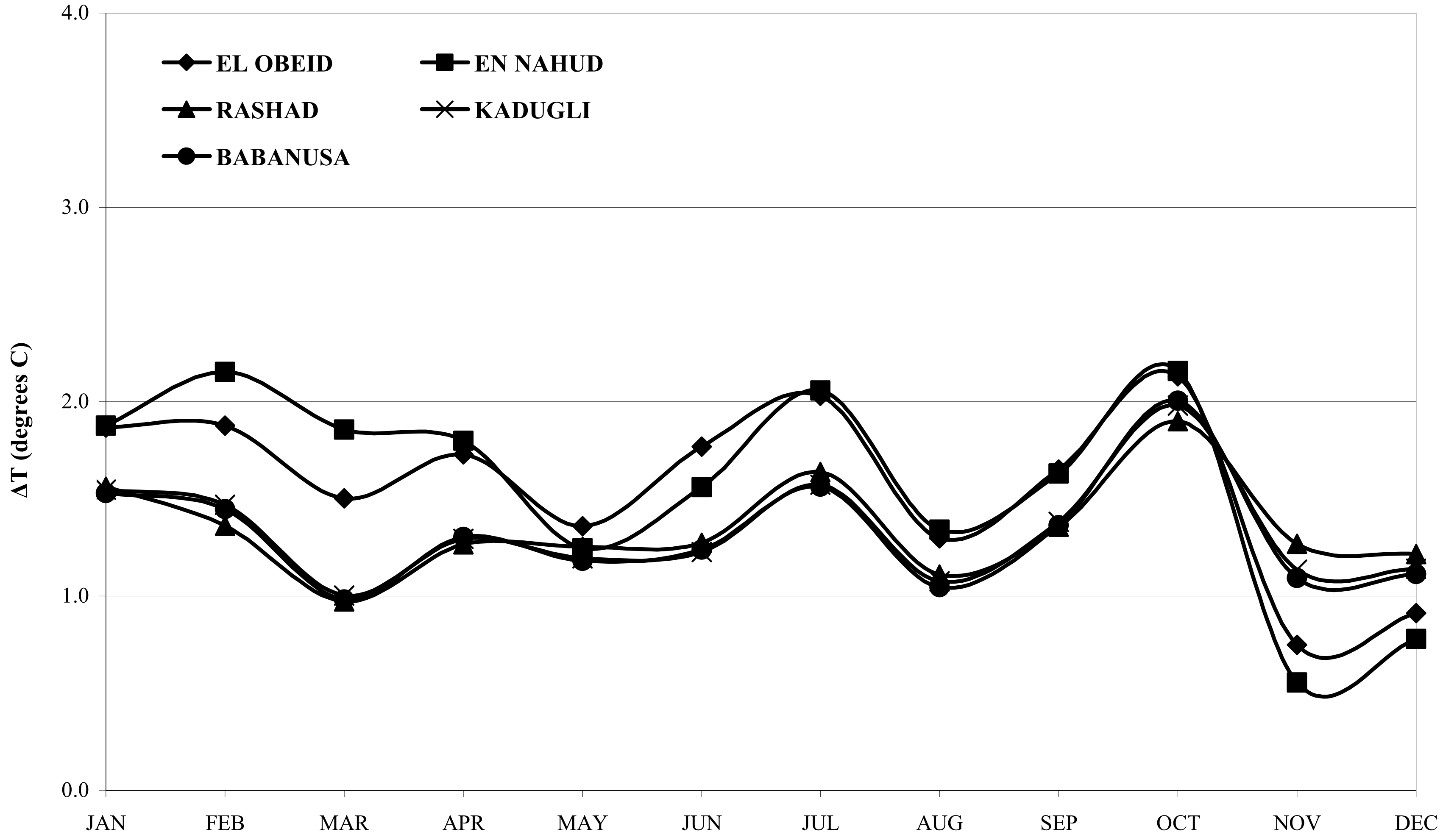


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Figure 1.20: Projected average monthly precipitation difference at El Obeid in 2030 from selected GCMs

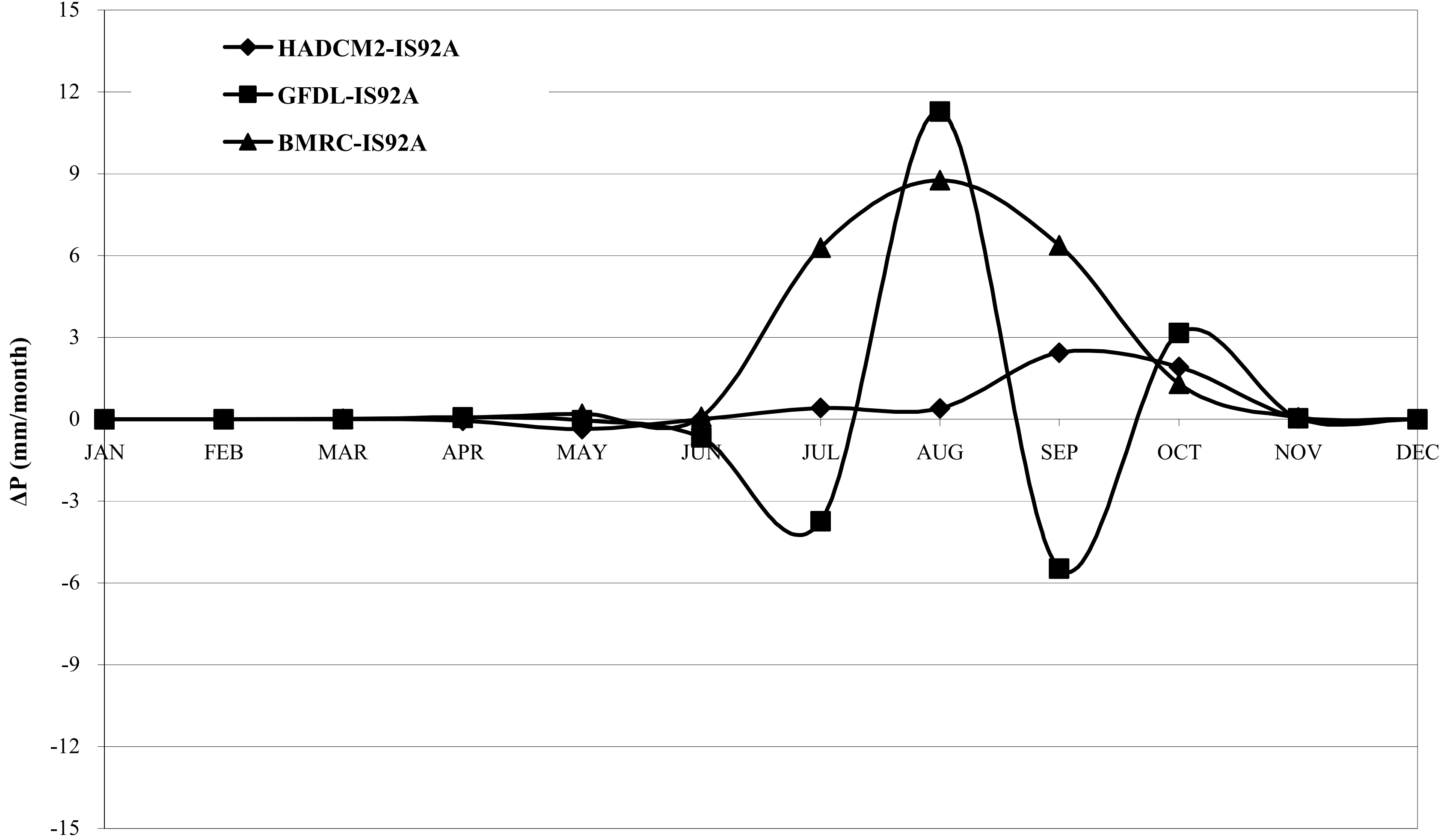


Figure 1.21: Projected average monthly precipitation difference at En Nahud in 2030 from selected GCMs

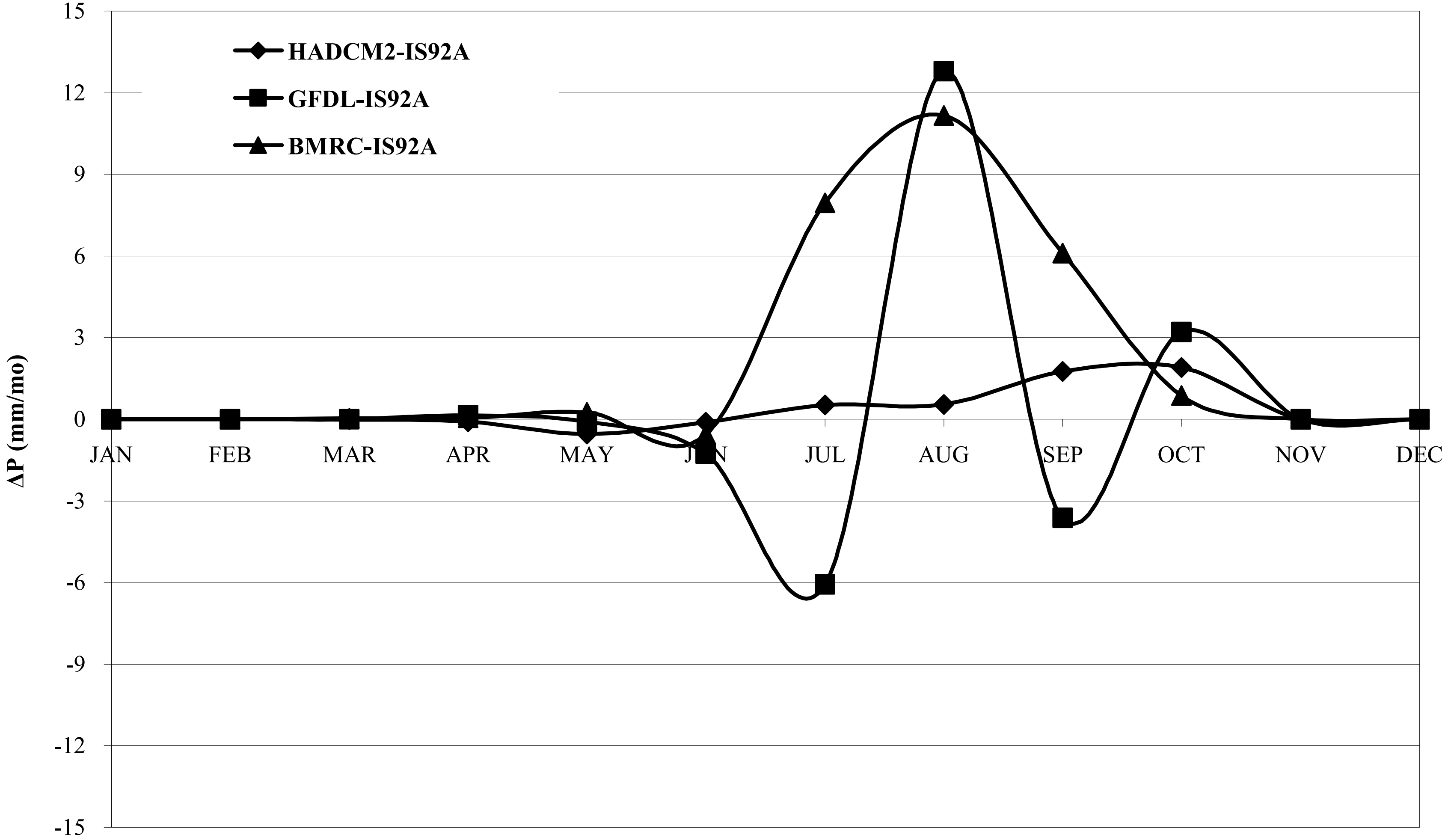


Figure 1.22: Projected average monthly precipitation difference at Rashad in 2030 from selected GCMs

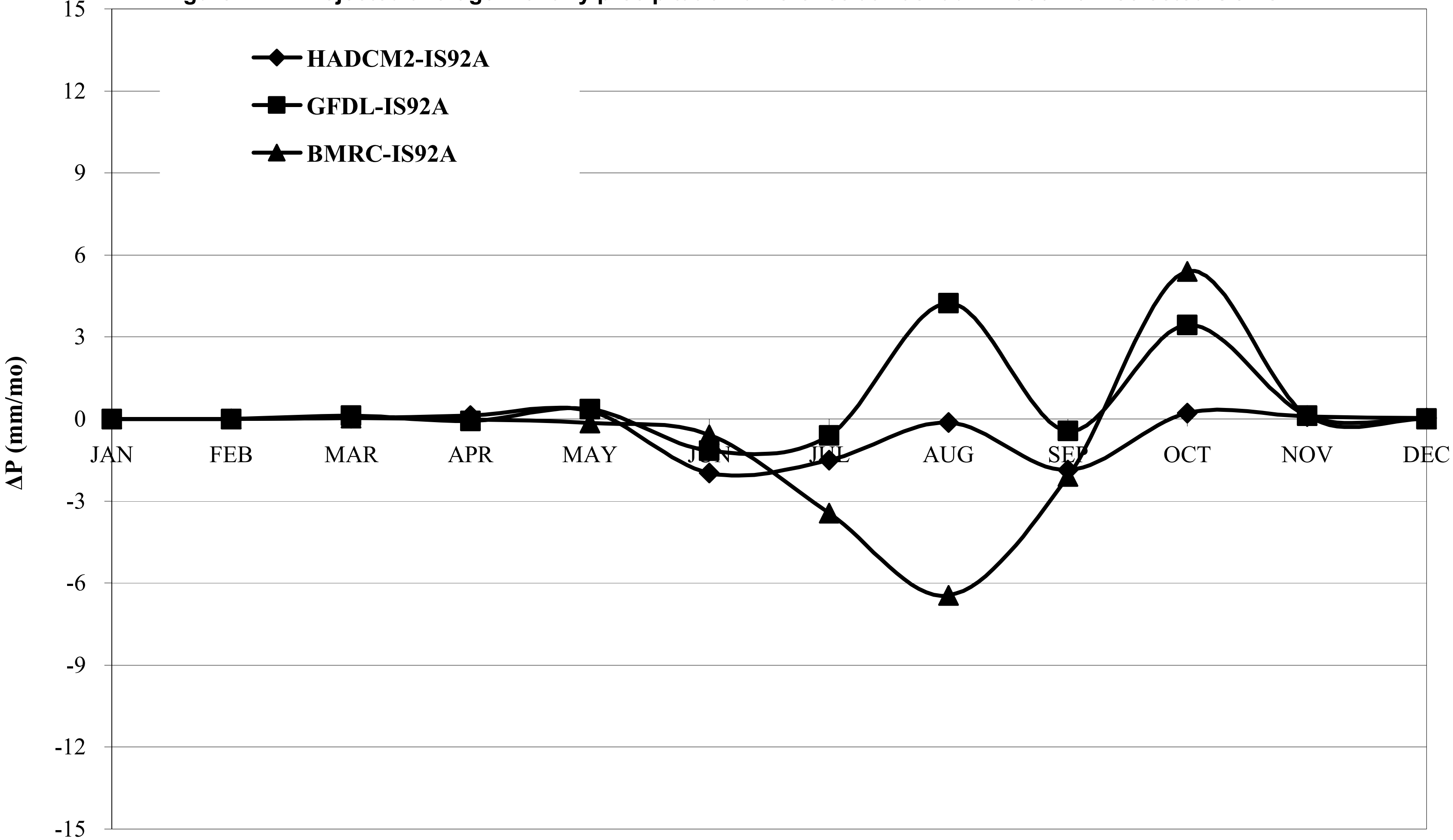


Figure 1.23: Projected average monthly precipitation difference at Kadugli in 2030 from selected GCMs

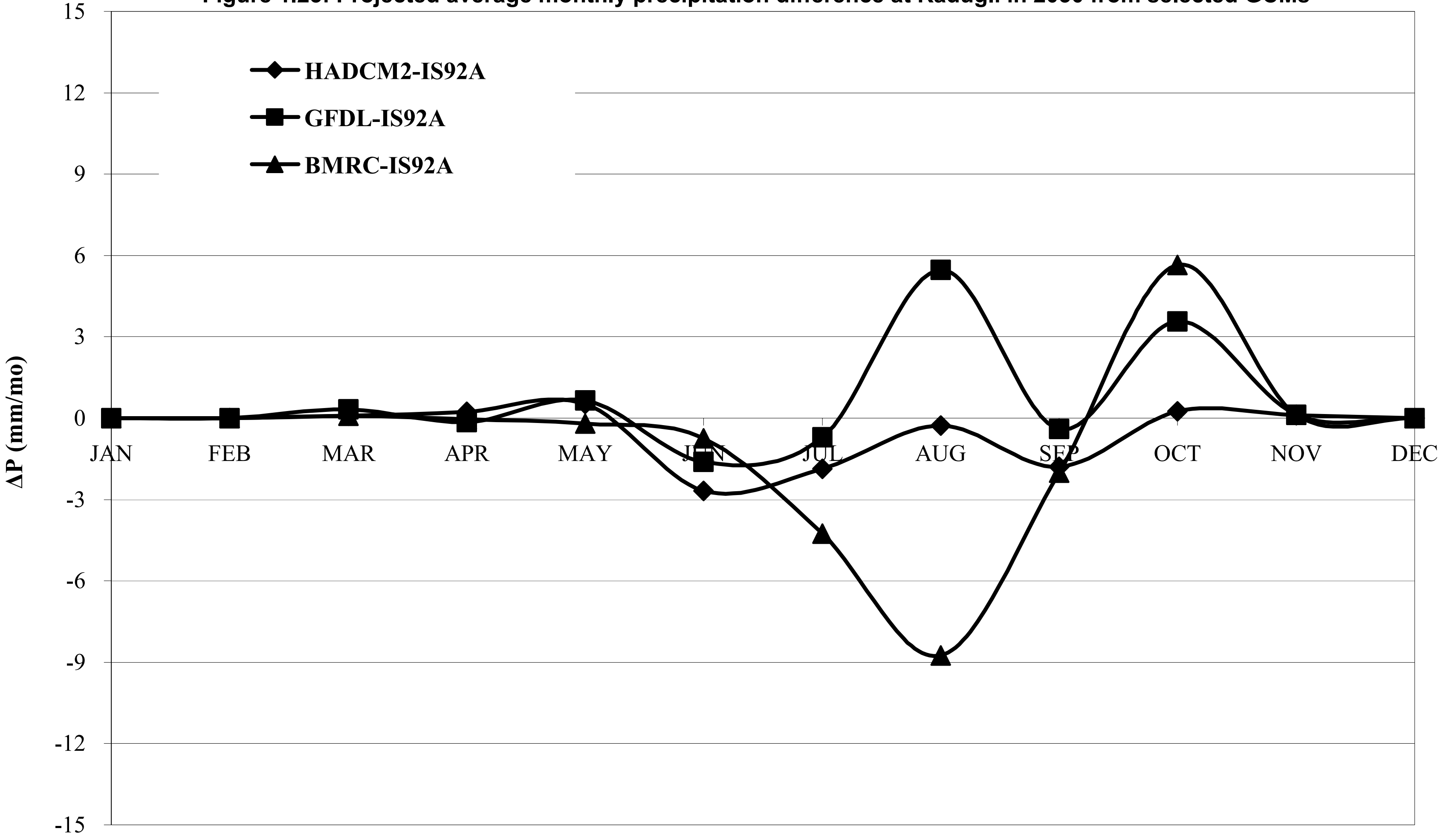


Figure 1.24: Projected average monthly precipitation difference at Babanusa in 2030 from selected GCMs

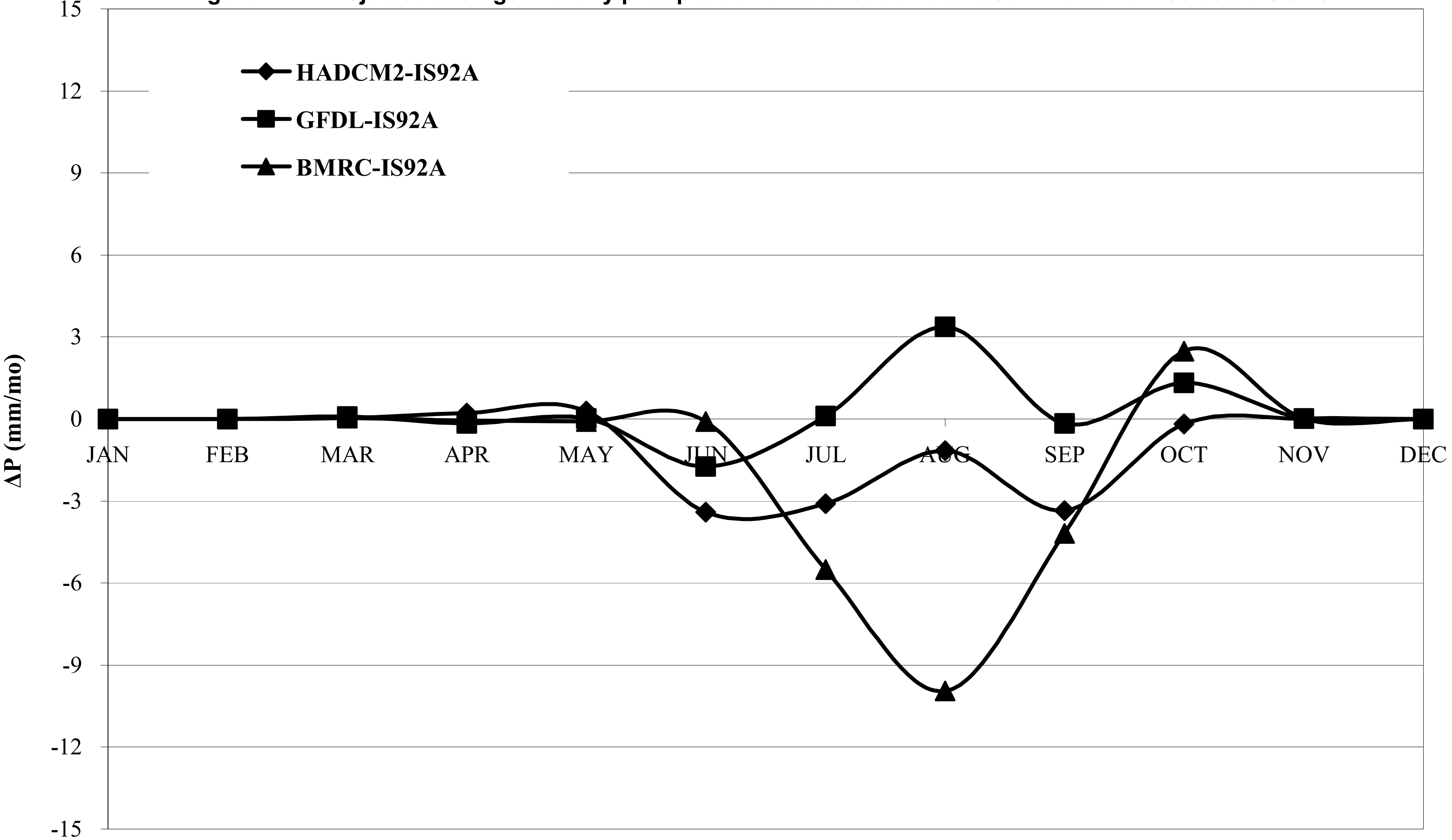


Figure 1.25: Projected average monthly precipitation difference at El Obeid in 2060 from selected GCMs

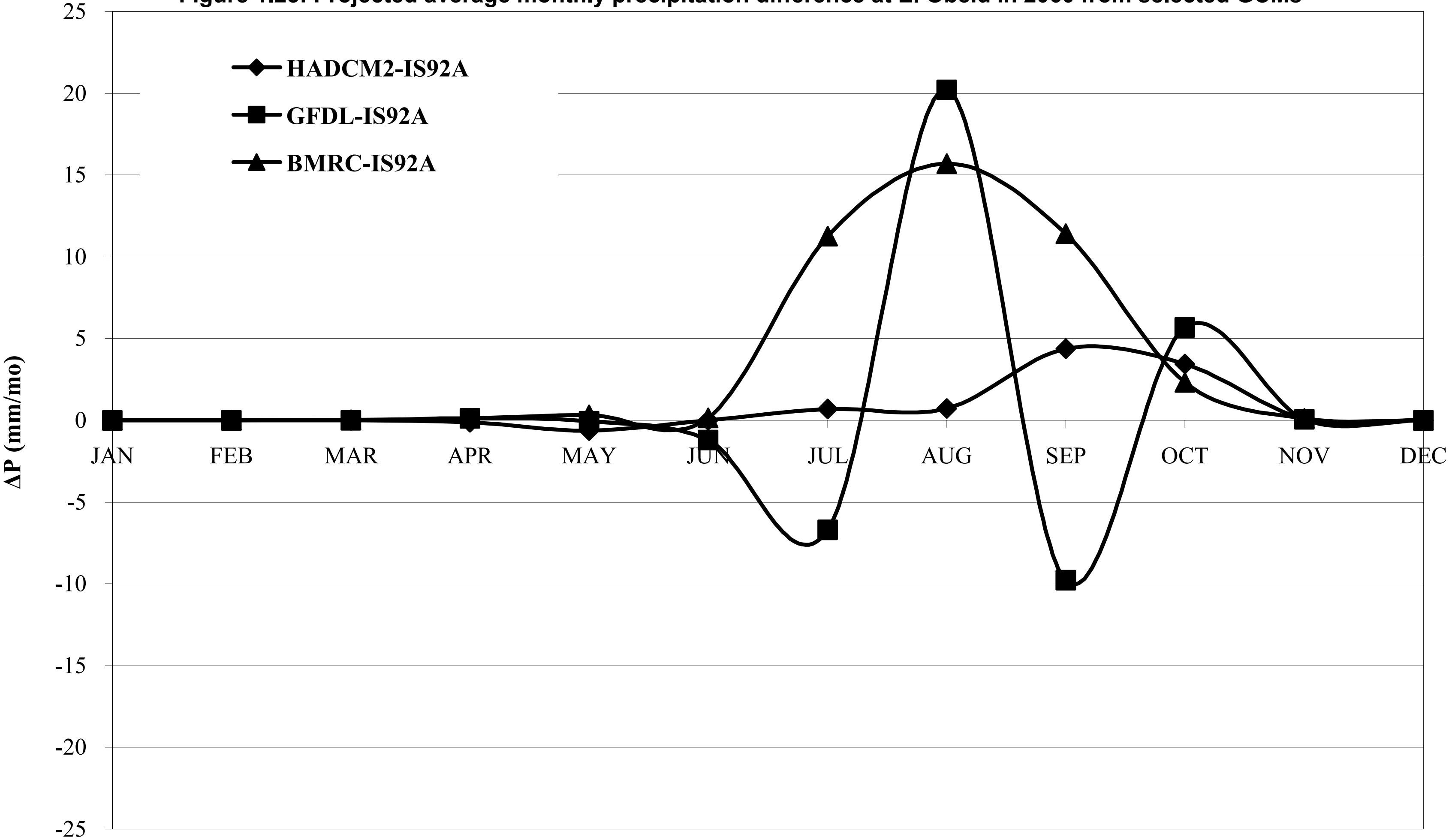


Figure 1.26: Projected average monthly precipitation difference at En Nahud in 2060 from selected GCMs

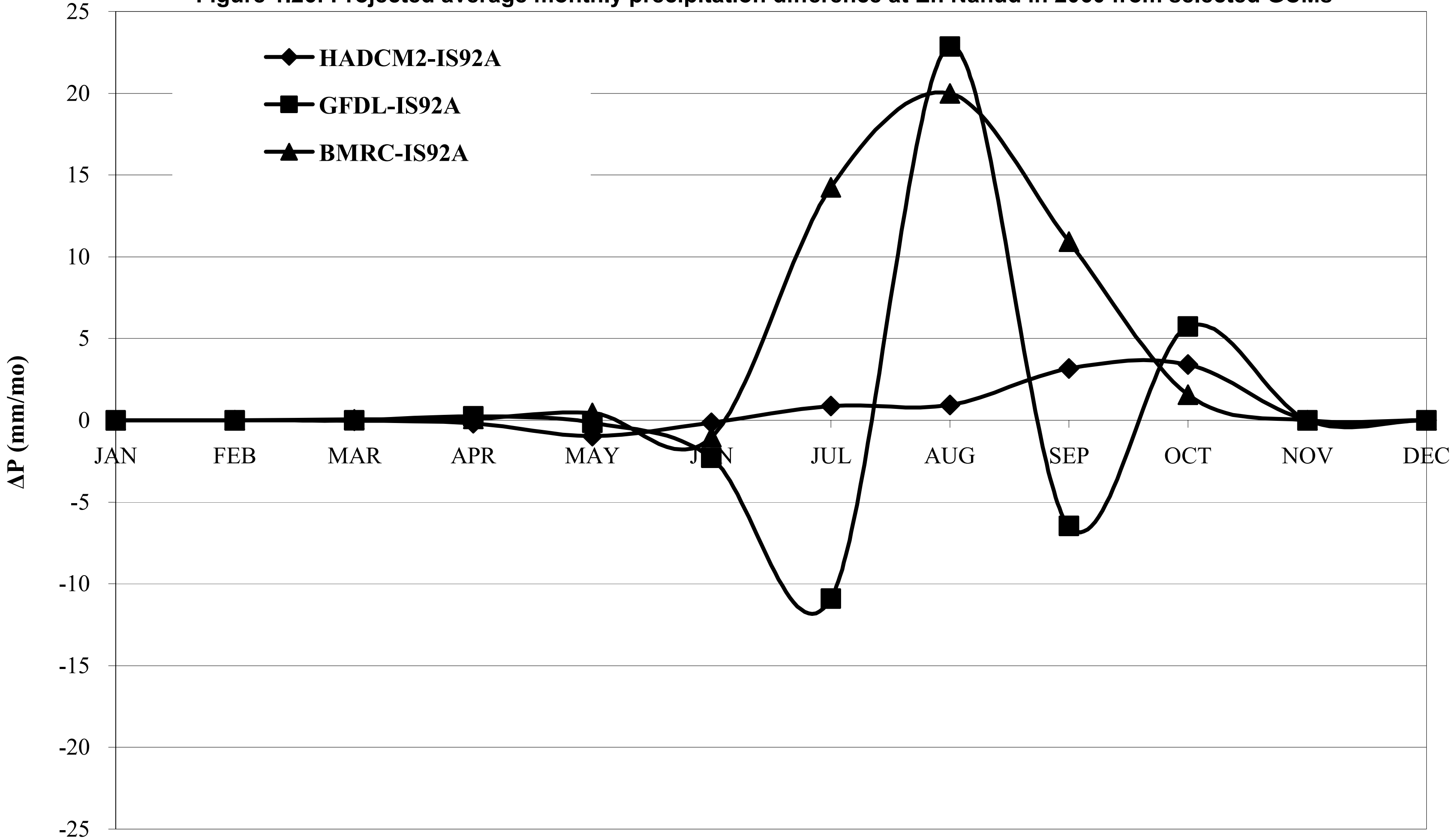


Figure 1.27: Projected average monthly precipitation difference at Rashad in 2060 from selected GCMs

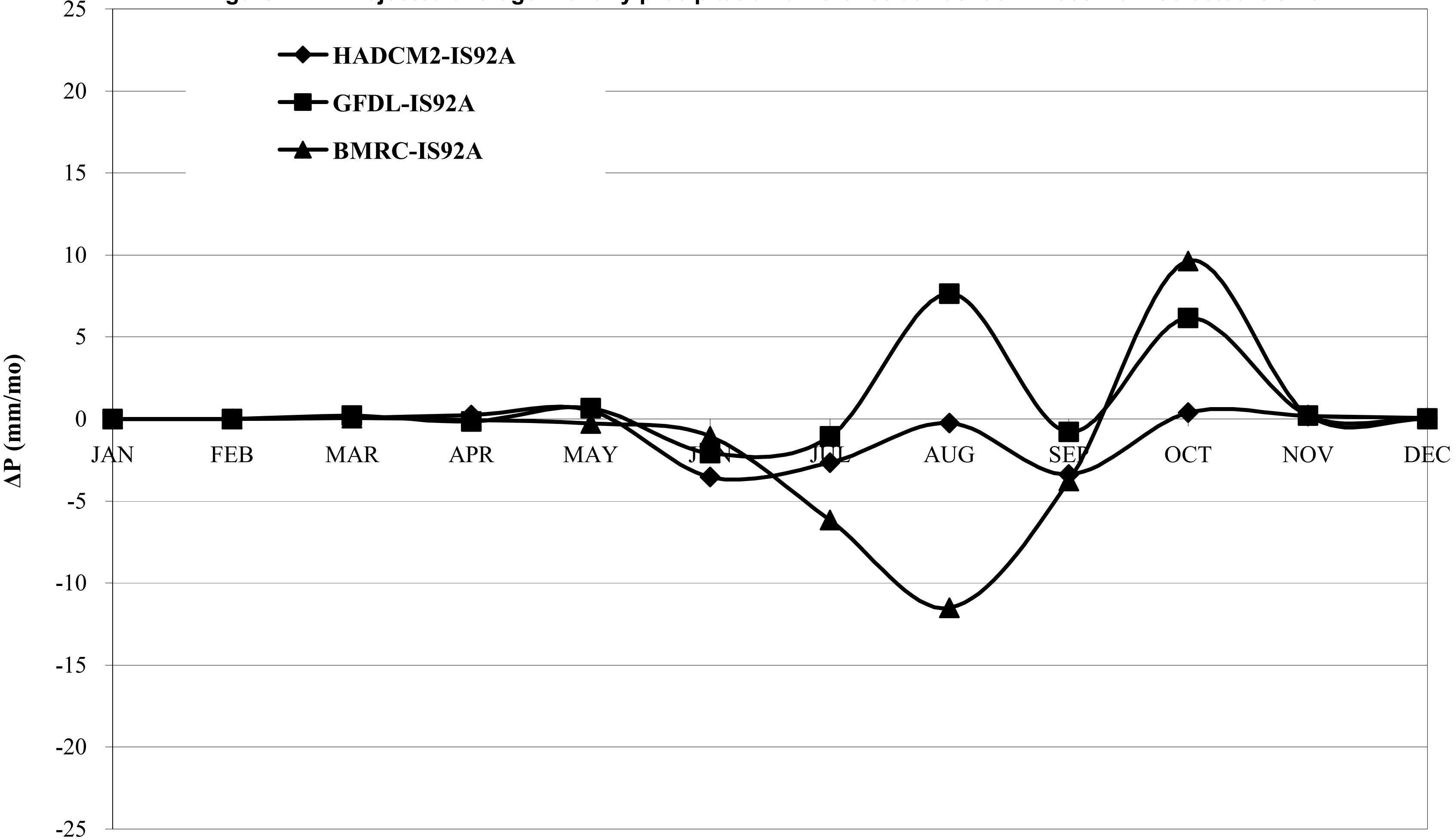


Figure 1.28: Projected average monthly precipitation difference at Kadugli in 2060 from selected GCMs

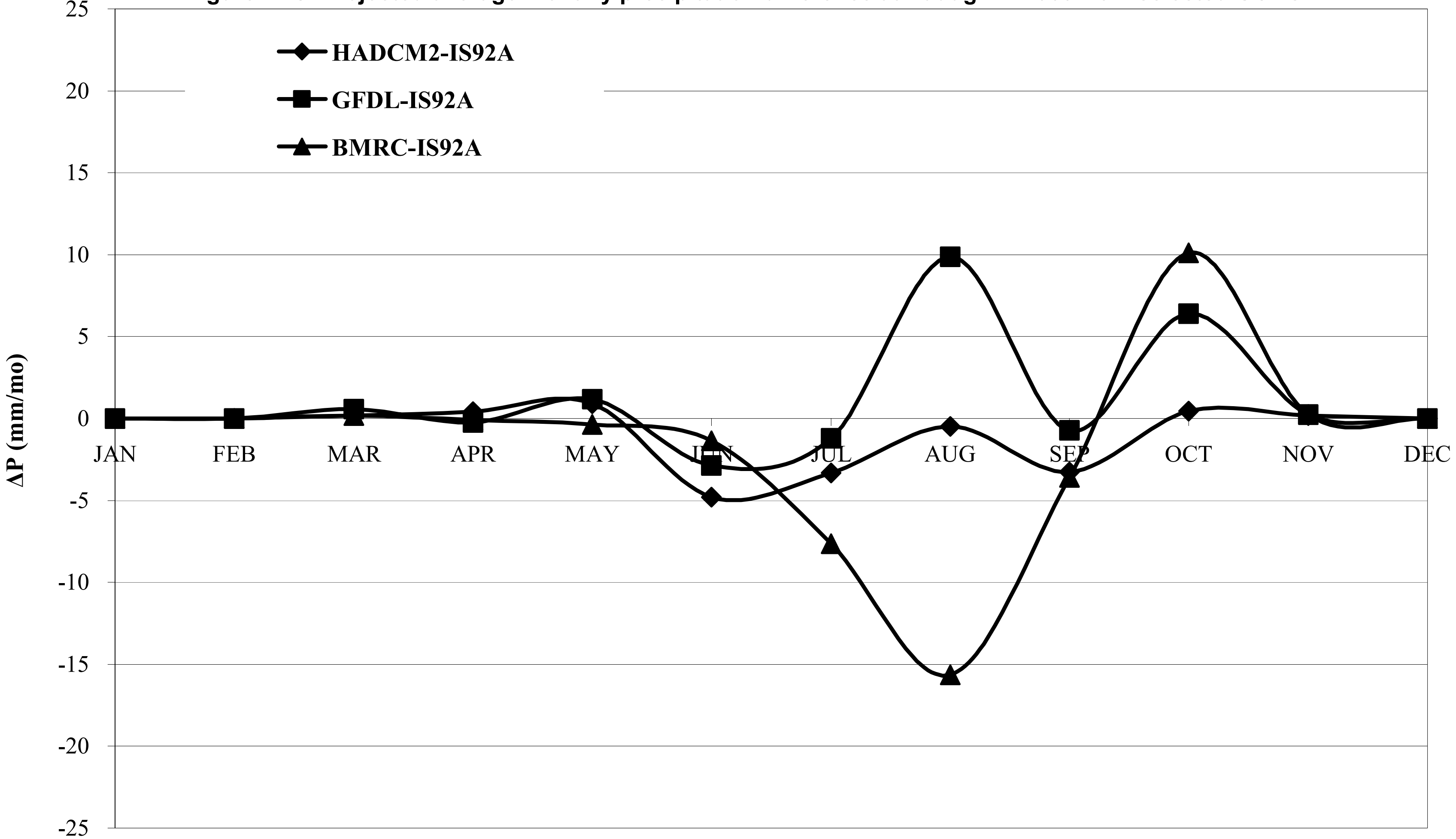


Figure 1.29: Projected average monthly precipitation difference at Babanusa in 2060 from selected GCMs

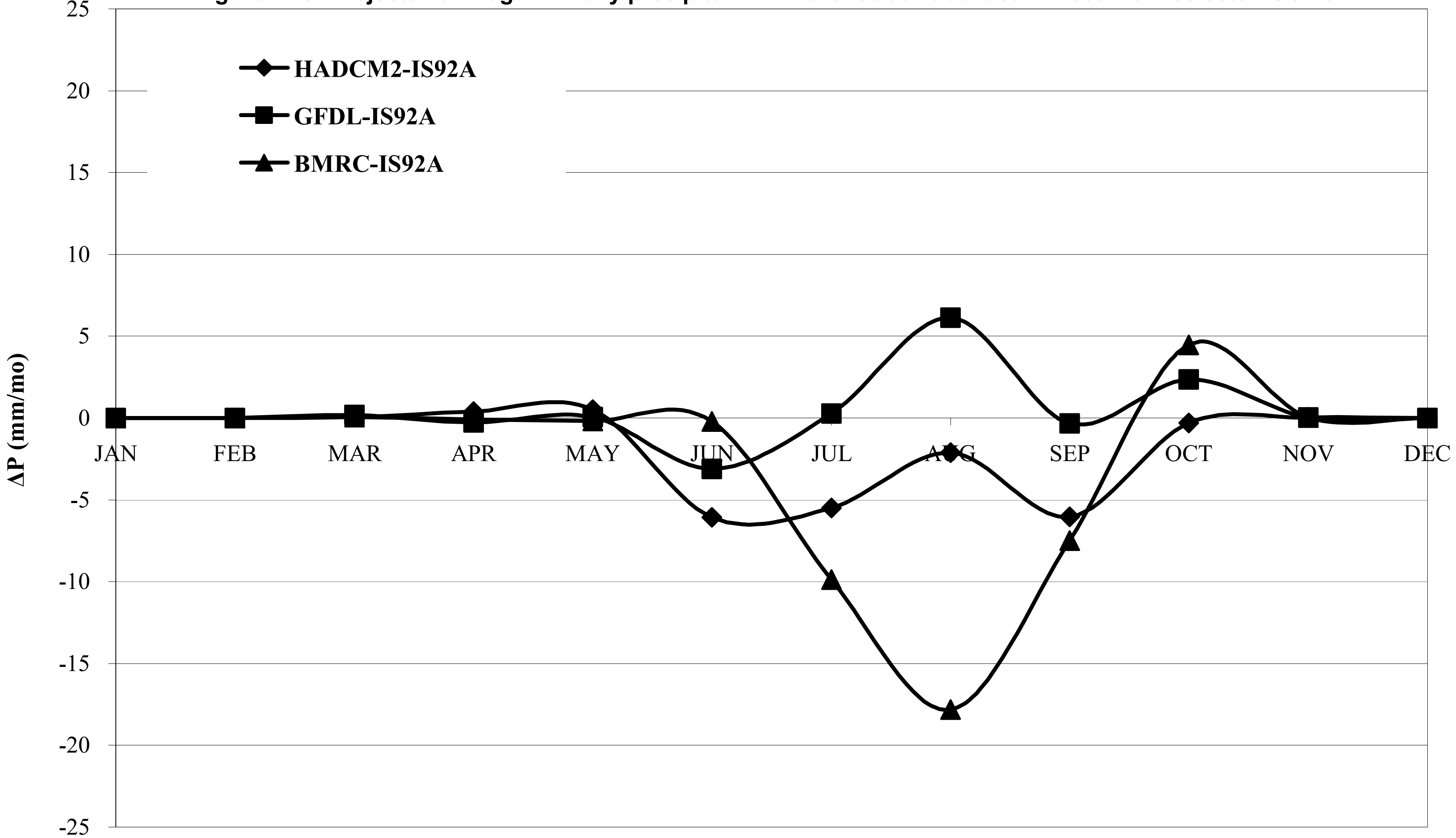


Figure 1.30: Projected average precipitation differences at all stations in 2030 from the HADCM2 GCM

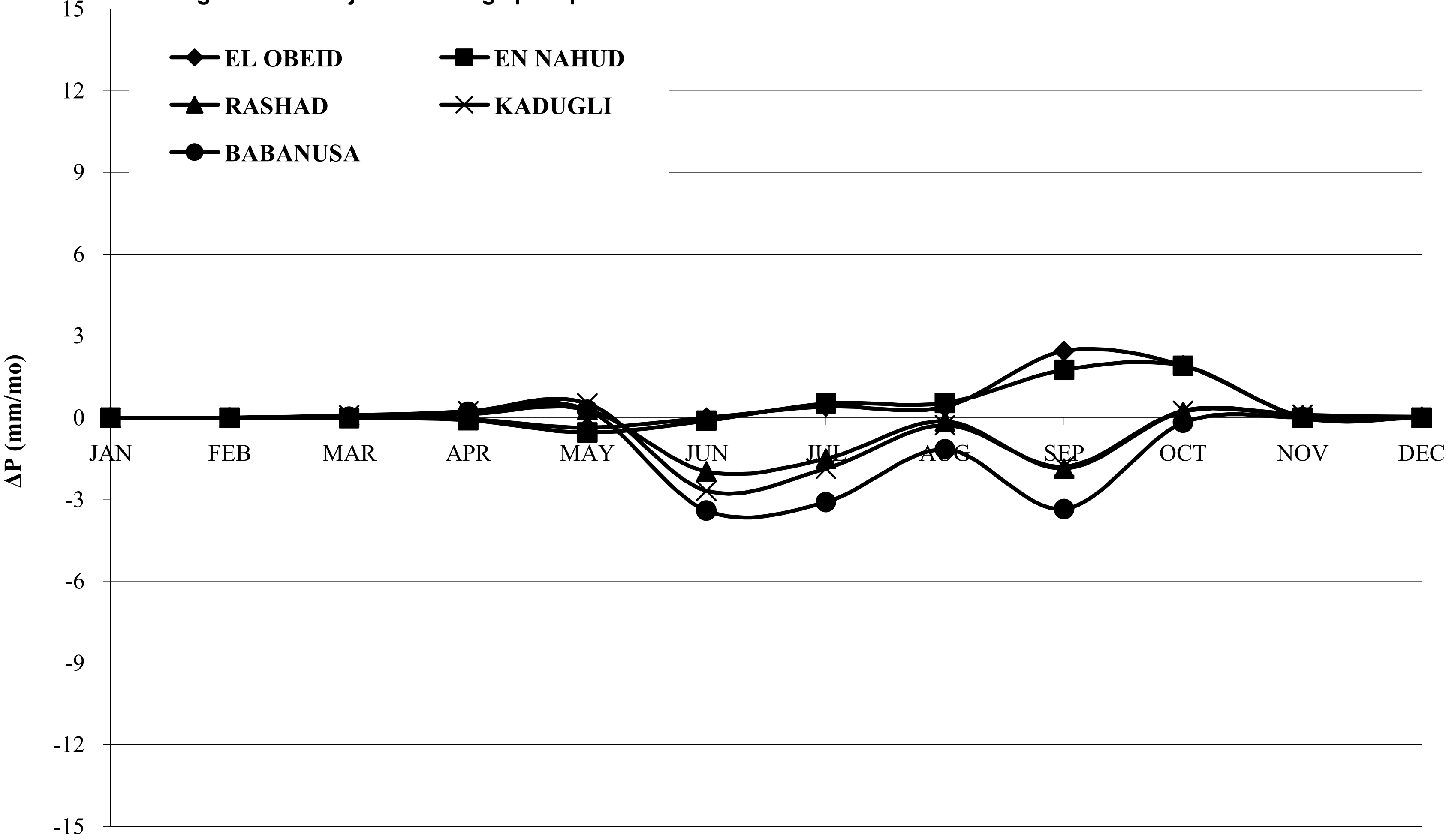


Figure 1.31: Projected average precipitation differences at all stations in 2030 from the BMRC GCM

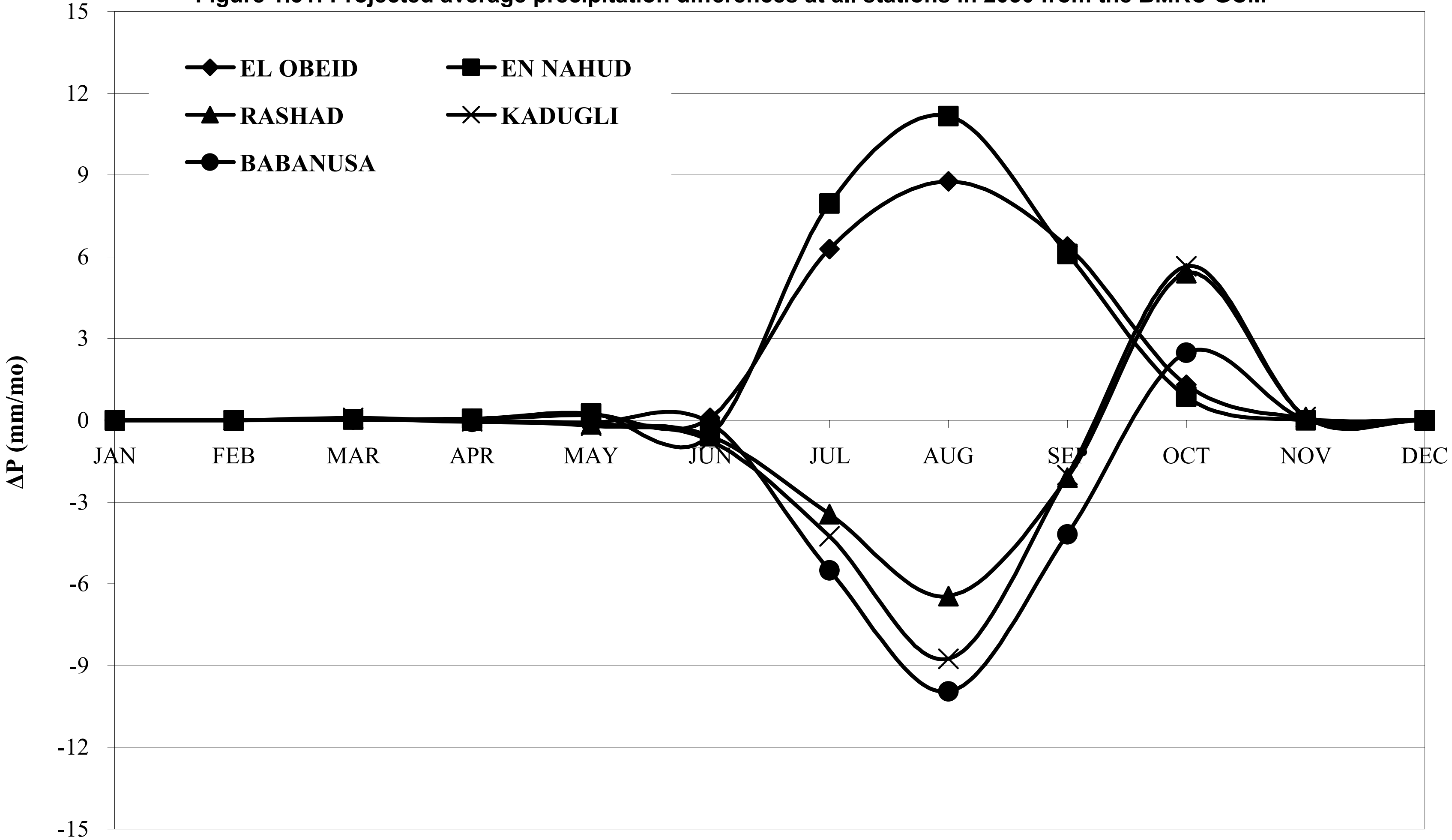


Figure 1.32: Projected average precipitation differences at all stations in 2030 from the GFDL GCM

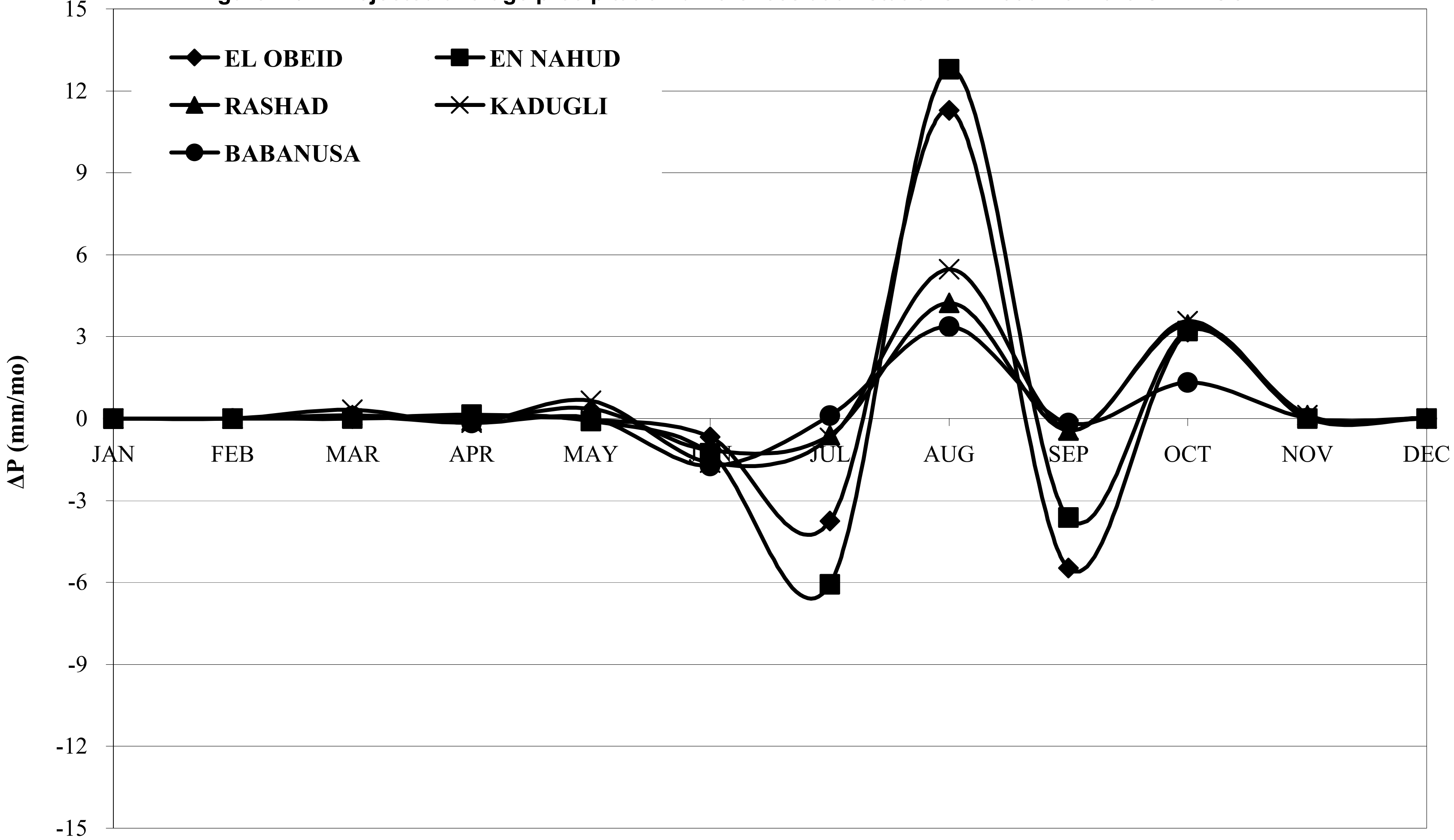


Figure 1.33: Projected average precipitation differences at all stations in 2060 from the HADCM2 GCM

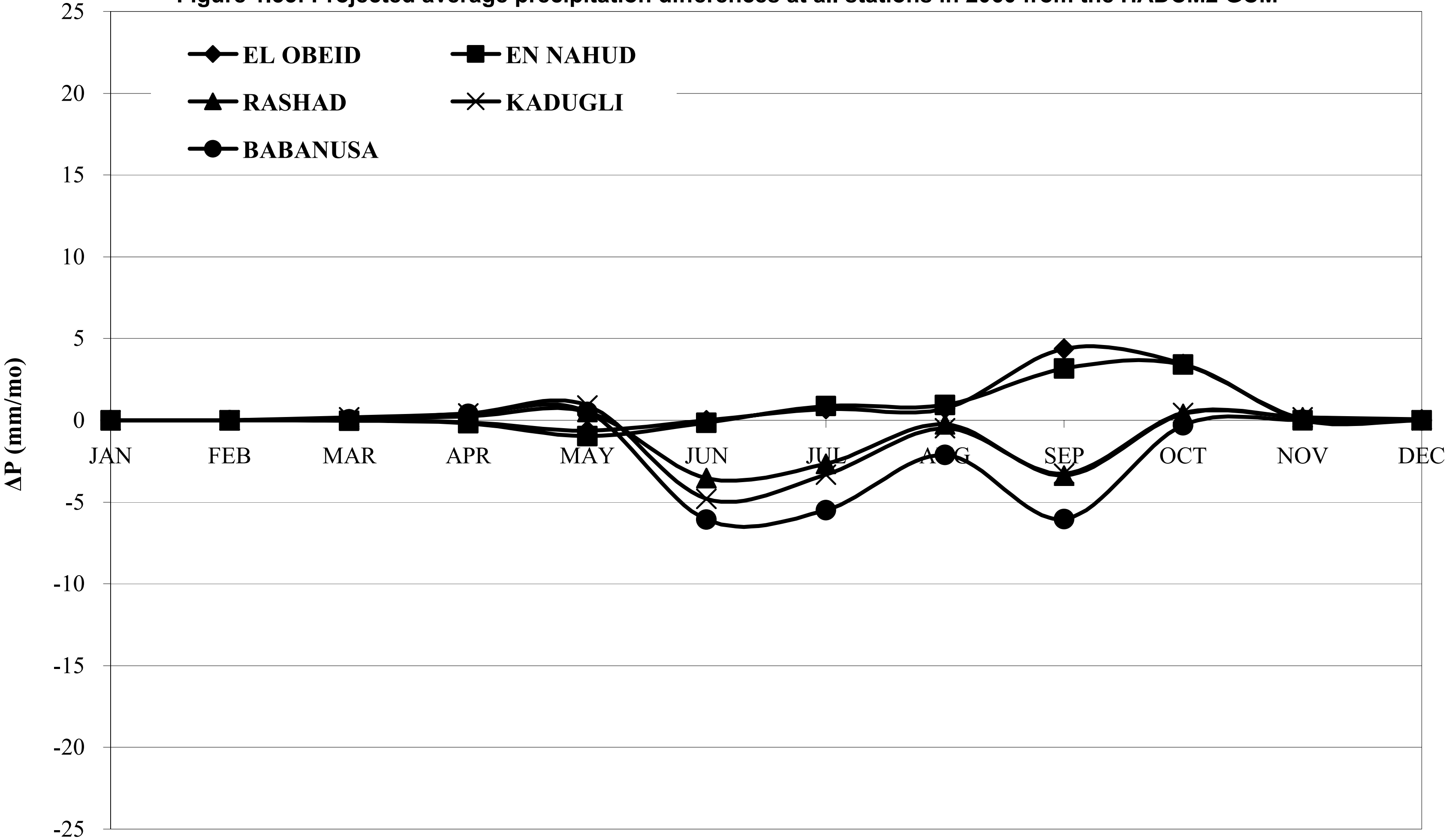


Figure 1.34: Projected average precipitation differences at all stations in 2060 from the BMRC GCM

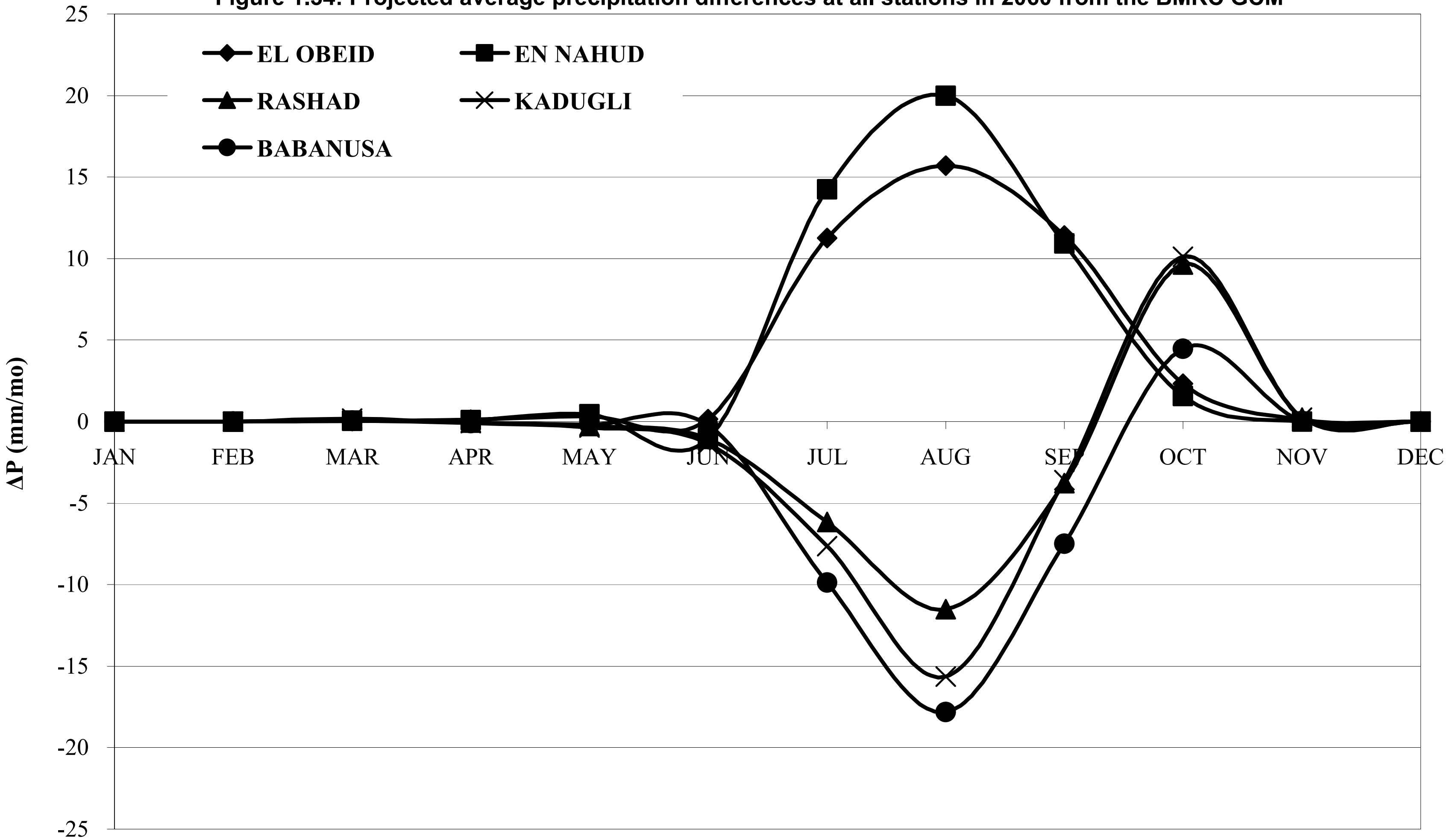


Figure 1.35: Projected average precipitation differences at all stations in 2060 from the GFDL GCM

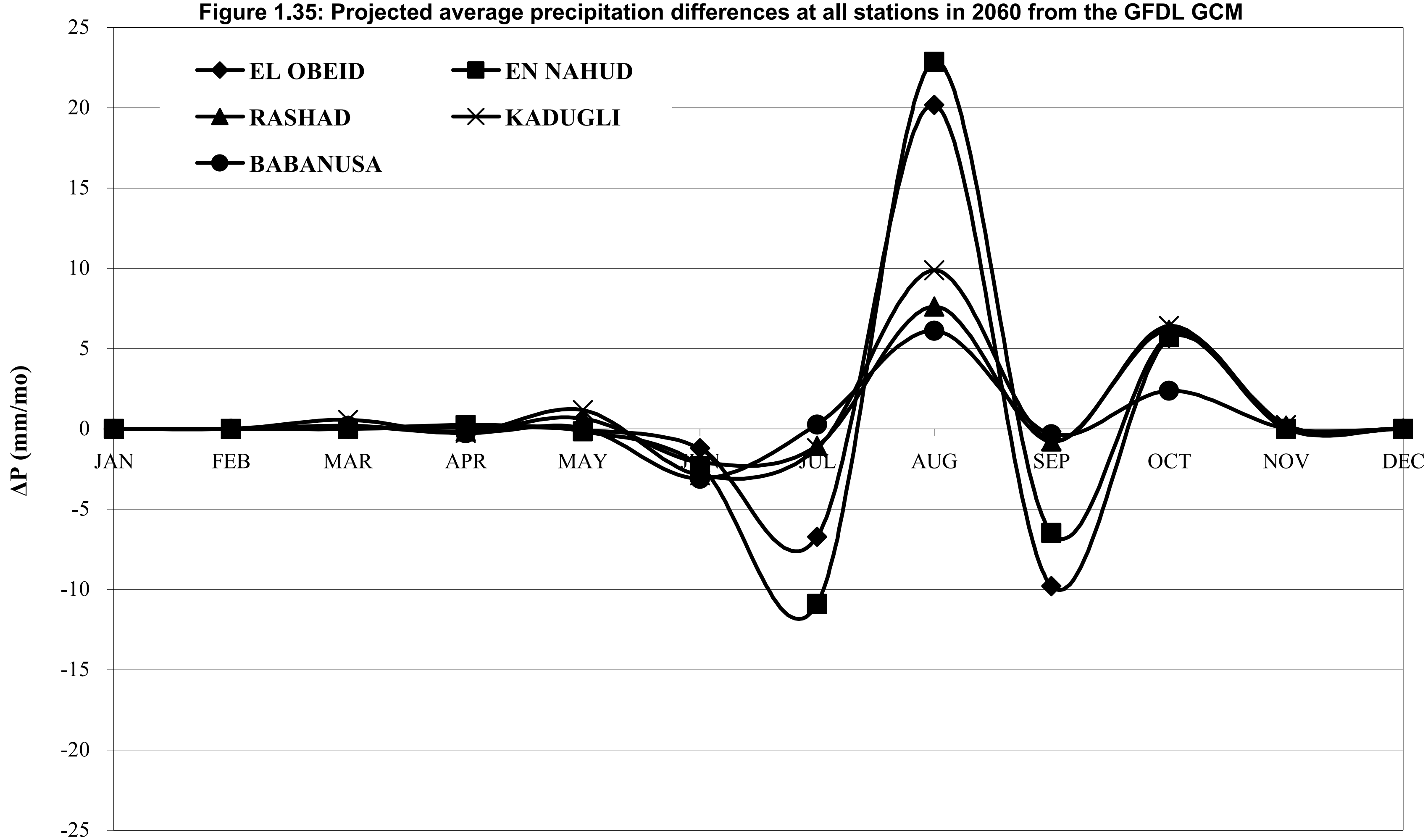


Figure 1.36: El Obeid Annual Rainfall Departure from normal in millimeters for the period 1961-1998

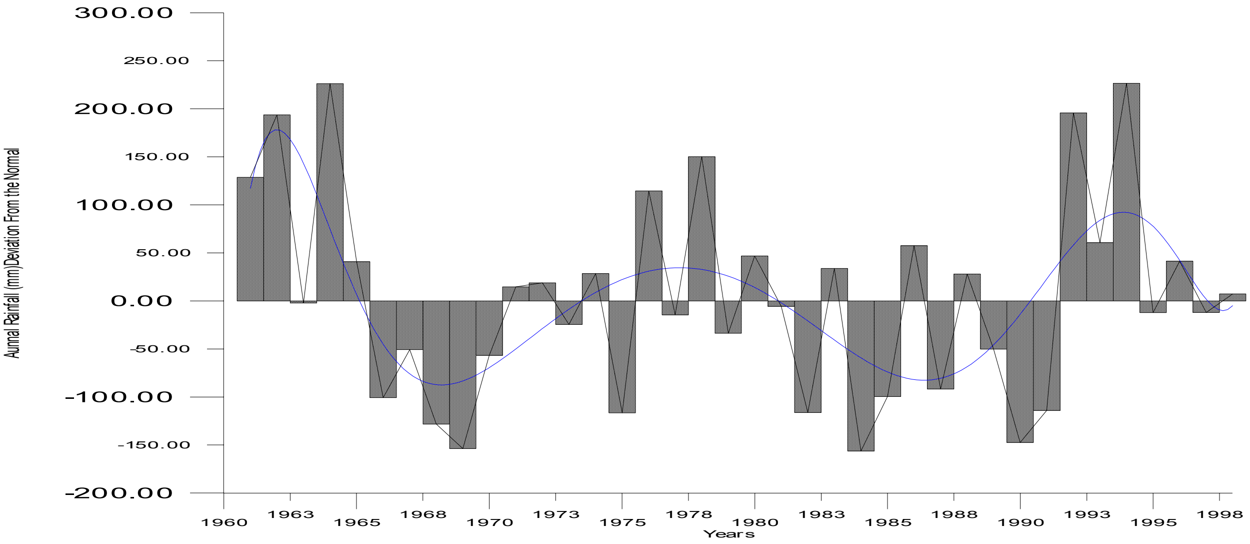


Figure 1.37: El Obeid Annual Mean Temperature Departure from normal in Degrees Centigrade for the period 1961-1998

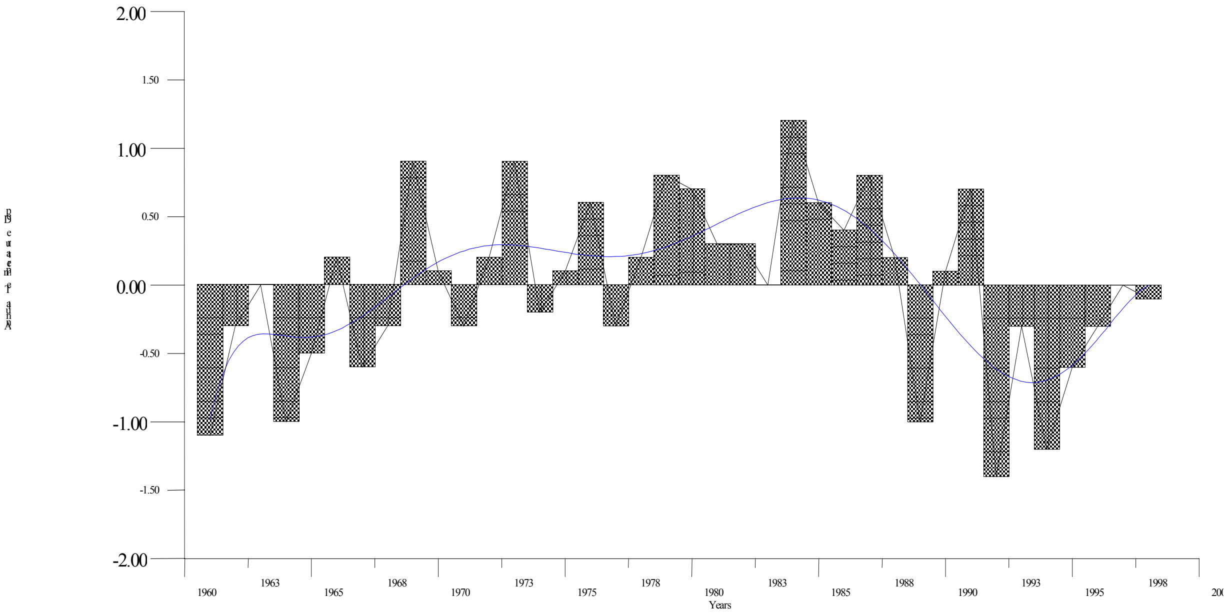


Figure 1.38: En Nahud Annual Rainfall Departure from normal in millimeters for the period 1961-1998

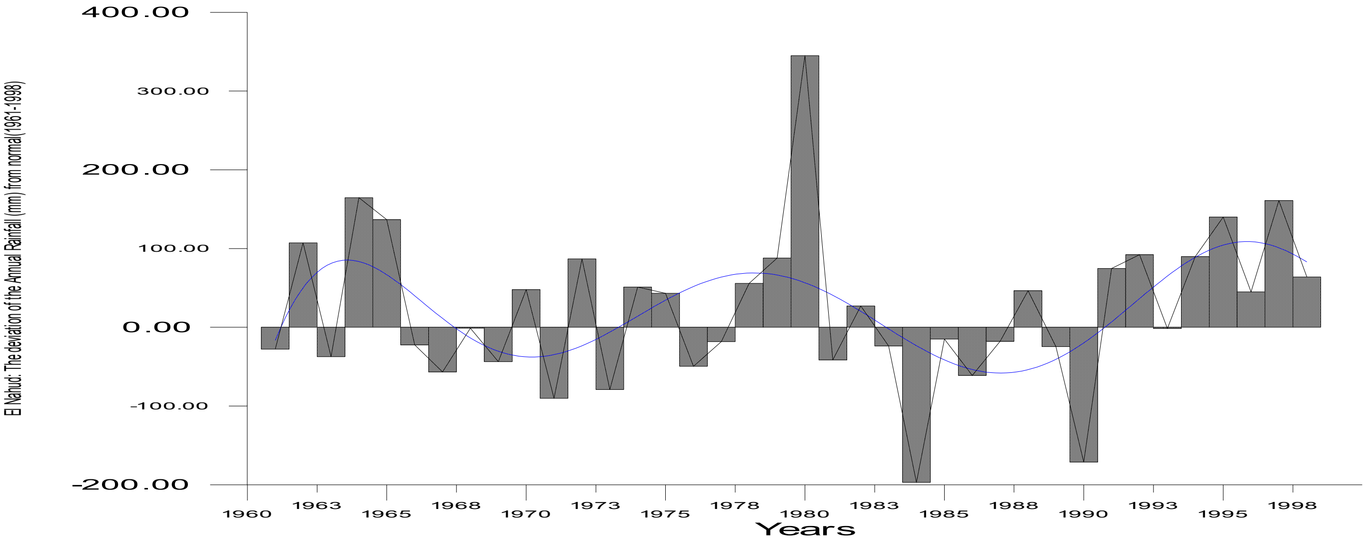


Figure 1.39: En Nahud Annual Mean Temperature Departure from normal in Degrees Centigrade for the period 1961-1998

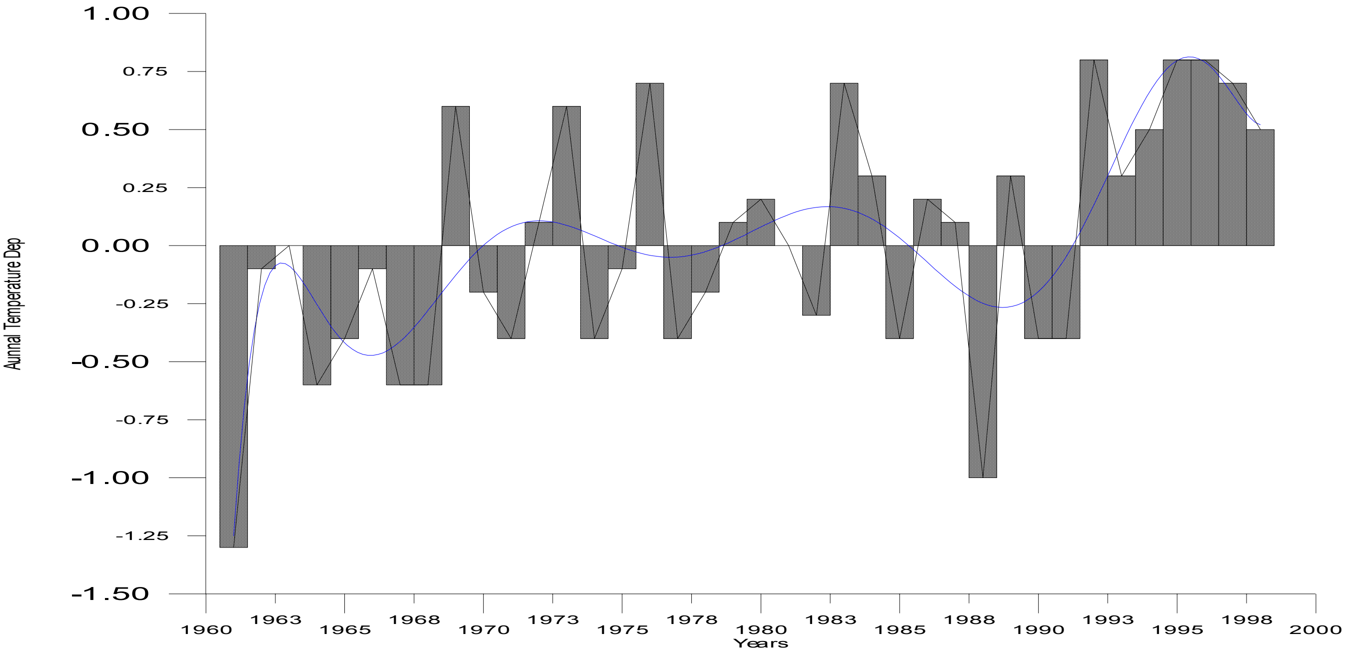


Figure 1.40: Rashad Annual Rainfall Departure from normal in millimeters for the period 1961-1998

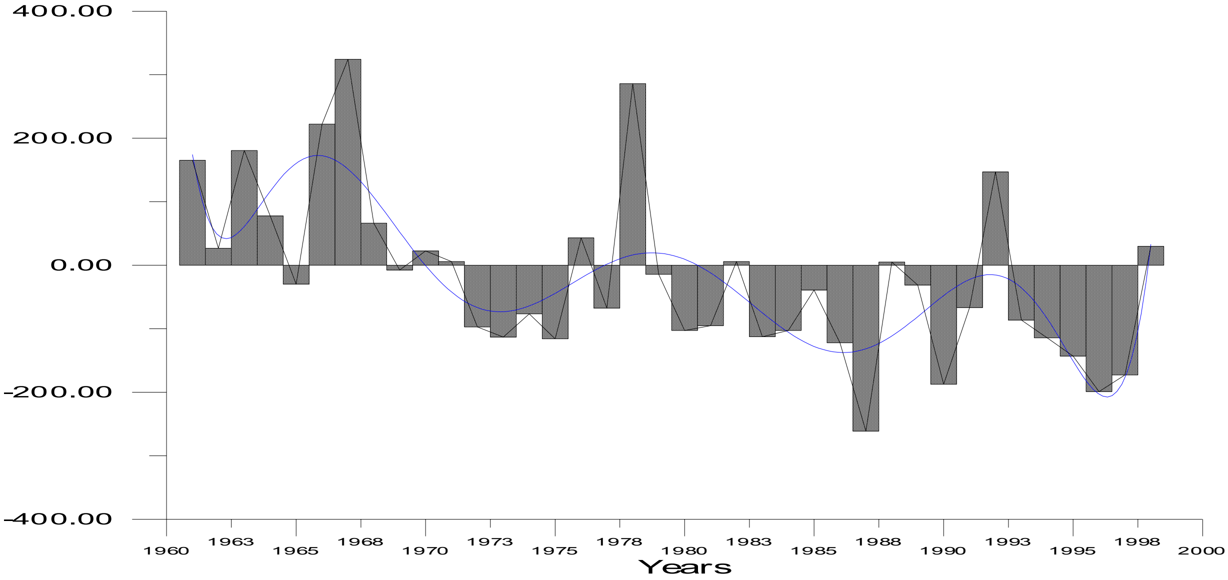


Figure 1.41: Rashad Annual Mean Temperature Departure from normal in Degrees Centigrade for the period 1961-1998

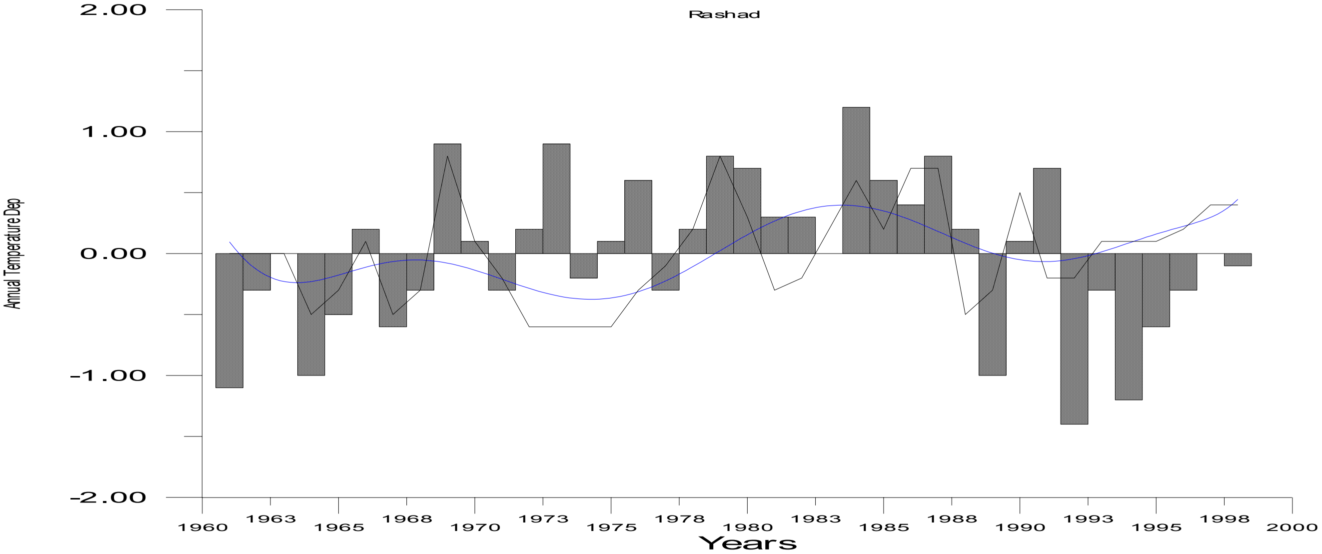


Figure 1.42: Kadugli Annual Rainfall Departure from normal in millimeters for the period 1961-1998

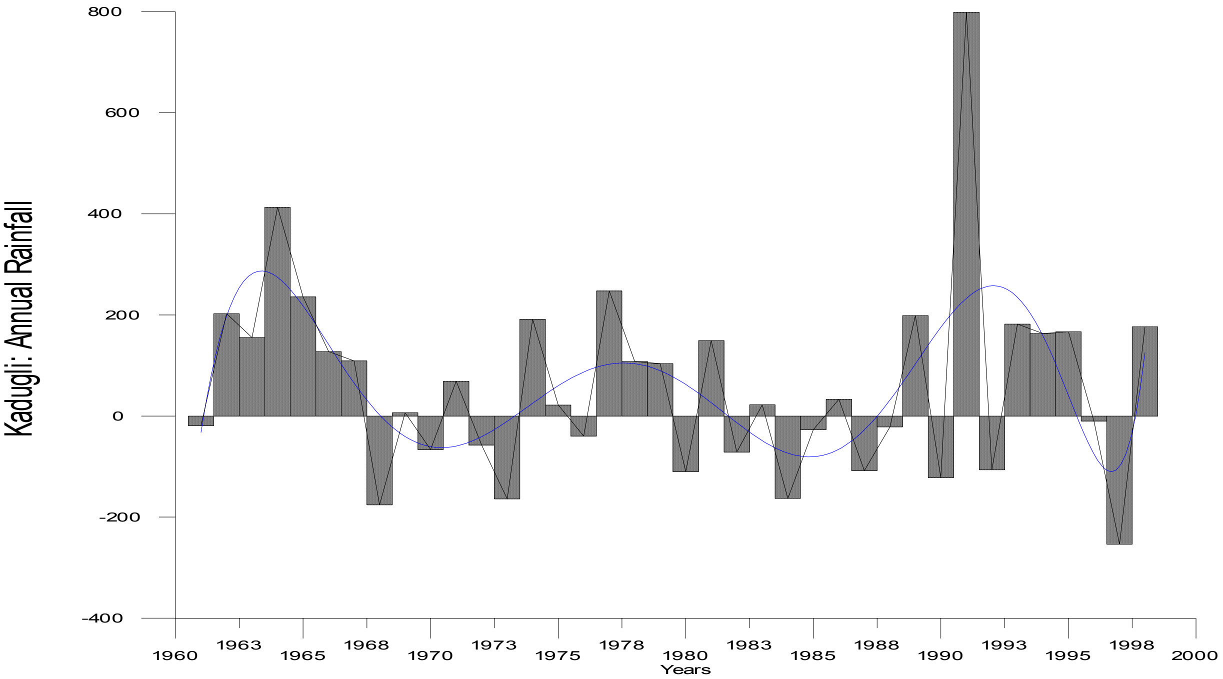


Figure 1.43: Kadugli Annual Mean Temperature Departure from normal in Degrees Centigrade for the period 1961-1998

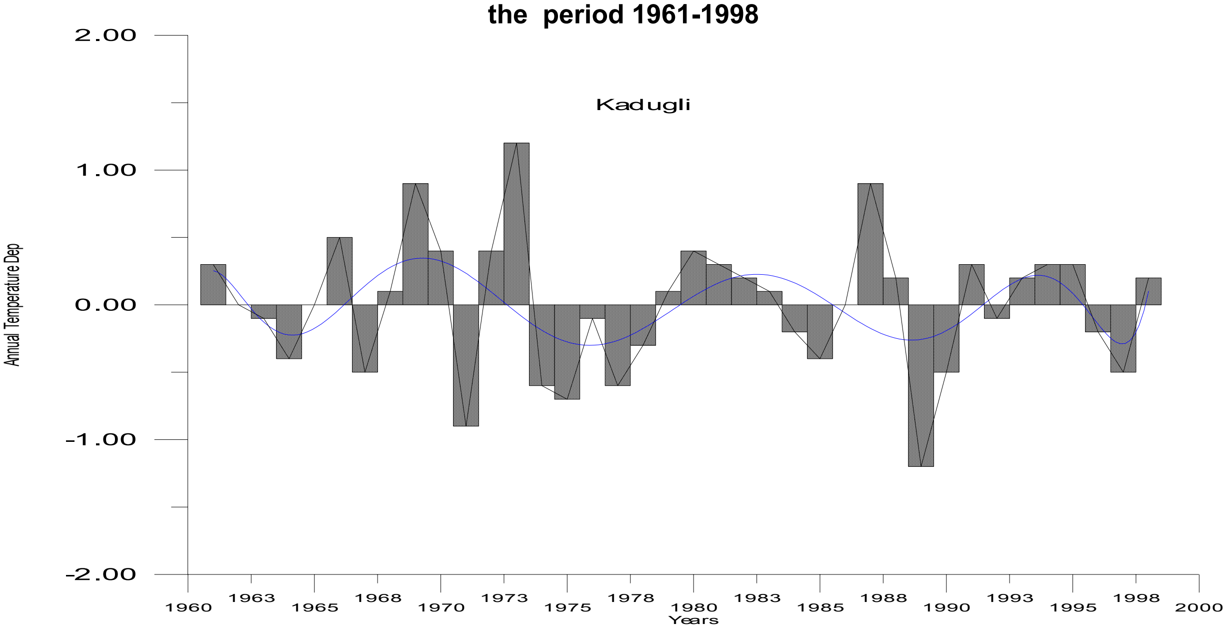


Figure 1.44: Babanusa Annual Rainfall Departure from normal in millimeters for the period 1961-1998

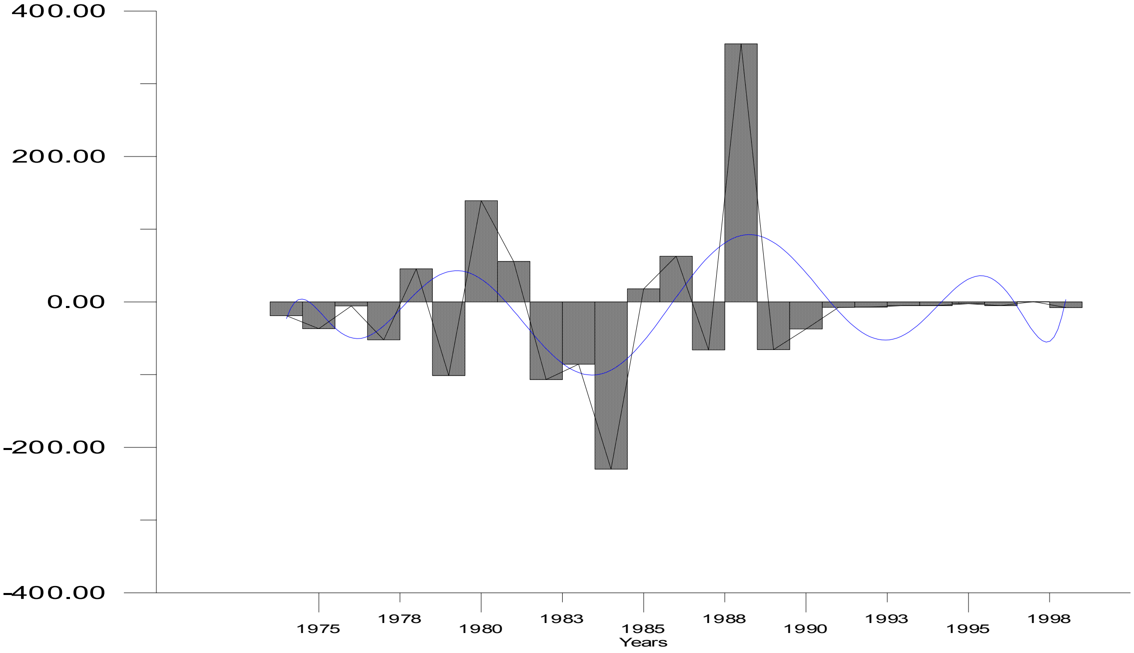
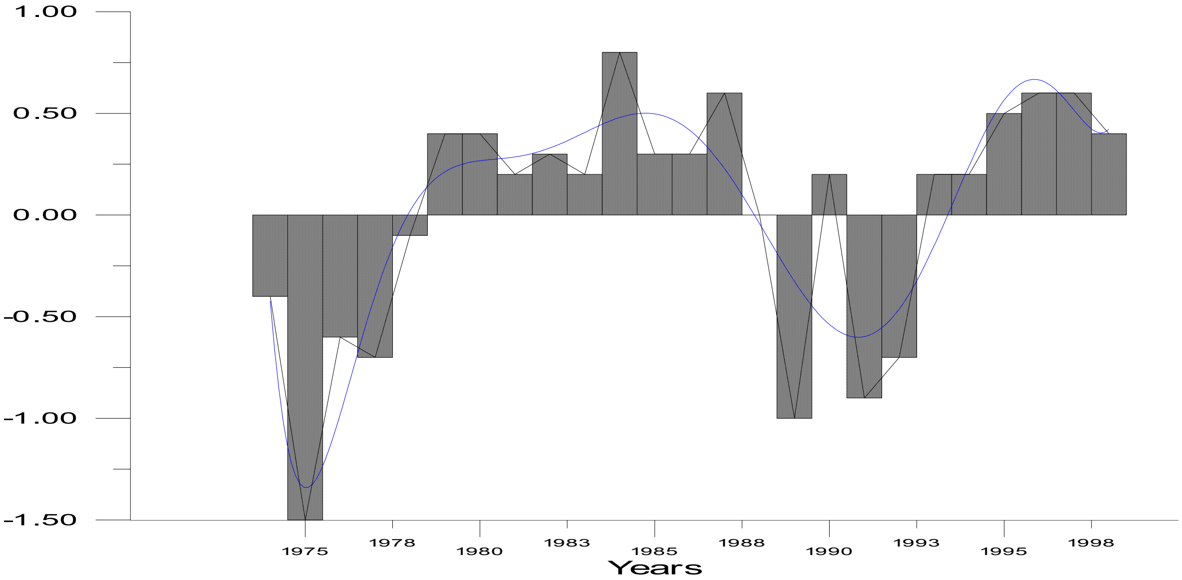


Figure 1.45: Babanusa Annual Mean Temperature Departure from normal in Deg. Centigrade for the period (1961-1998)



2. Agriculture & Forestry

2.1 Background

2.1.1 General

Sudan can be ecologically divided into five vegetation zones according to rainfall patterns from North to South. These are:
Desert: (0-75 millimeters of precipitation) comprising about 36% of the country;
Semi-desert: (75-300 mm) comprising about 20%;
Low rainfall savannah: (300-900 mm) constitute about 24%;
High rainfall savannah: (900-1800 mm) constitute 12%; and
Flood plains and montane vegetation: (500-2000 mm) about 8%.

Over half the area of Sudan can be characterized as marginal, arid land. Yet, agriculture is the backbone of Sudan's economy - highlighting the nation's vulnerability to the impacts of a changing climate. Agricultural production in Sudan is primarily subsistence agriculture, practiced under three main farming systems: irrigated, mechanized rain fed, and traditional rain fed. Of these, traditional rain fed agriculture is the most widely practiced and perhaps the most vulnerable to crop failure.

Forests are under great stress in Sudan. In the mid-fifties, forests constituted about 36% of the total area of the Sudan (90,000,000 km2). Today, most of this forest land has been depleted to meet the demands for fuel wood and timber. According to the FAO, in the 1980s the size of forests was estimated at only 20% of the total area of the Sudan. Recently, it was estimated at just 15% (National Forest Inventory, 1998). At present, the annual consumption rate of woody forest products far exceeds the allowable cut. The consumption is approximately 16 million cubic meters annually while the allowable cut is approximately 11 million cubic meters. There are now vast areas, completely bare of forest cover except for isolated, scattered natural forests remaining outside forest reserves.

Forested areas are inversely proportional to population density, as 68% of Sudan's forests are in the South where just 15% of the population lives, and only 15% of the Northern states area is forested (as of 1998), where the remainder of the population lives. Sudan's more important forest may be the Gum Arabic Belt, which lies within the low rainfall Savannah zone. The term Gum Arabic Belt is used to denote a zone of approximately 500,000 square kilometers, which extends across Central Sudan, between latitude 10° and 15° N. The Gum Arabic Belt accounts for one fifth of the country's total area. The Belt is home to roughly one fifth of the population of Sudan and two thirds of its livestock population.

Sudan supplies 80% of the gum arabic consumed globally, making the product one of the country's most important cash crops and the most important non-wood forestry product. Harvested from *Acacia senegal* (Hashab) and *Acacia seyal* (Taleh), gum arabic is extremely important to rural populations in that it provides income during the dry season, at a time when it is most needed. In 1998, nearly 24 billion tonnes of gum arabic were exported (see Table 2.1).

The Gum Arabic Belt protects 46% of the total area of Sudan from desert encroachment as it acts as a natural barrier. However, the Belt is also a site of intense, diverse, and often conflicting human activity. This includes irrigated agriculture, mechanized rain fed agriculture, forestry and grazing.

Table 2.1: Sudan exports commodities 1996-1998 ***(thousand 1997 US$)***

		1996		1997		1998	
Commodity	**Units**	**Qty.**	**Value**	**Qty.**	**Value**	**Qty.**	**Value**
Cotton	Pal.	480,941	128,209	433,292	105,662	395,596	95,546
Gum Arabic	Million tonnes	15,551	29,531	26,966	22,428	23,622	23,666
Sesame	Million tonnes	157,405	141,132	171,826	117,312	167,231	104,752
Groundnut	Million tonnes	2,176	1,301	14,782	764	25,440	14,197
Vegetables & fruit	Million tonnes	9,609	5,328	7,582	2,875	10,071	3,614
Sheep	Thousand heads	1,187	7	123	71	1,705	98
Cattle	Thousand heads	571	1	18	1	51	2
Camel	Thousand heads	15	3	33	6	93	20
Meat	Thousand heads	12	28	44	32	13	30

Source: Annual report, Sudan bank

2.2 Role of Agriculture & Forestry in the Sudan Economy

Agriculture dominates Sudan's foreign trade, contributing more than 80% of exports, primarily in the form of unprocessed materials. The main exported agricultural commodities are cotton, sesame, gum arabic, livestock, groundnut, fruits, and vegetables. Agriculture, as a share of GDP, is less prominent, accounting during the 1985 to 1997 period for between 29 and 46%, as shown in Table 2.2.

Table 2.2: Gross domestic product of Sudan and of agriculture at factor cost ***(million 1997 US$)***

Year	National GDP	Agricultural GDP	Agricultural Share (% GDP)
1985/86	1390.9	529.8	38
1986/87	1052.6	379.7	36
1987/88	747.1	229.4	31
1988/89	415.2	138.4	31
1989/90	174.5	52.8	30
1990/91	49.6	14.2	29
1991/92	34.6	11.9	34
1992/93	27.1	10.3	38
1993/94	13.9	5.6	40
1994/95	7.3	3.2	44
1996	6.1	2.8	45
1997	6.5	3.1	47

Source: Ministry of Finance & National Economy.

In view of the role that agriculture plays, the government of Sudan, in the last decade, has developed a number of strategic plans in which food security is a prominent theme. To achieve food security, several programs have been designed to increase both crop and livestock production. The contribution of agriculture to GDP has increased, reaching 47% in 1997, due mainly to increased agricultural production and to an increase in livestock products.

2.3 Role of the Kordofan Region in the Sudan Economy

Kordofan is a critical region in Sudan for Agriculture & Forestry production. It produces a number of different cash crops such as groundnut, cotton, and gum arabic - more than 75% of Sudan's gum arabic harvest. The states are also considered the center of the country's livestock production. In addition, many food crops are produced in the region, such as millet (in the North) and sorghum (in the South). These two crops are considered to be extremely dependent on climate. Most of the millet and sorghum harvest is consumed locally. (See Tables 2.21, 2.22, and 2.23 for corresponding data.)

Of Kordofan's total area, 40% is desert, and another 14% is considered to be at severe or very severe risk of desertification. In view of Kordofan State's central role in national gum arabic production, its importance as an agricultural zone in the country, and the dependence of these products on the climate system, it has been chosen as the focal region for the V&A assessment.

2.3.1 Kordofan Agriculture & Forestry Systems

In Kordofan, irrigated agriculture is insignificant compared to rain fed systems. The rain fed farming sector contributes most heavily to the country's annual agricultural crop production. The region produces about 40% of the total millet production, 15% of sorghum, 25% of groundnut, 30% of sesame, and 5% of maize. Rain fed agriculture in Kordofan is divided into mechanized rain fed sub-sector and smallholder traditional rain fed sub-sector - a division that is based on farm resources (i.e., land, tools, equipment, technology, credit, etc.).

The region can also be divided by cropping pattern types. These are (a) millet-based cropping pattern (mainly in the northern part of the state) and (b) sorghum-based cropping pattern (mainly in the southern part of the state). In addition, systems of forestry have developed over the years. Often these developed in response to climate and soil type – e.g., the traditional system of gum arabic production, as described in the following subsections.

2.3.2 Systems of Cropping and Animal Husbandry

Traditional farming systems in the Kordofan States are based on systems of cropping and animal husbandry. The major crops grown are millet and sorghum. Other crops produced are groundnut and sesame (major cash crops) watermelon, roselle, cowpea, maize, cotton, and okra. Animals raised are mainly sheep, goats, and camels in the North, and cattle and goats in the South. Production systems in the region can be classified into the following:

- **Nomadic:** More than 50% of the gross household revenue of nomadic families depends on livestock, and as a result, they migrate in search of water and forage. This system can be divided into two subsystems: the *camel nomadic subsystem* (Kababiesh and Kawahla are the primary practicing tribes; camel is the main livestock raised), and the *desert sheep nomadic subsystem* (sheep are the main livestock species; the Shanabla are the primary practicing tribe).
- **Transhumance System:** In this system, people migrate seasonally, following traditional grazing routes. Millet, sesame, and groundnut are cultivated along the route, but cropping activities play a relatively minor role in the system. The primary groups - the Messeriya and Hawazma - generally raise cattle, sheep, and goats.
- **Sedentary System:** This system includes both agricultural and livestock components, and is dominated by the cropping of sesame and groundnut. Sheep are the dominant animal, and the Nuba are the dominant ethnic group in the system. The activities of the sedentary system have traditionally been based on bush-fallow cultivation system. The major crops are millet and sorghum.

2.3.3 Bush-Fallow System of Forestry

The Tiffen Report (1983) described this system of shifting cultivation as a technique for restoring soil fertility after a period of cultivation. The process consists of relatively short periods of cultivation followed by relatively long periods of fallow. During the fallow period a certain amount of natural vegetation re-growth takes place. Eventually the vegetation is cut and/or burnt, and the process begins again, with a new round of cultivation.

The gum tree, *Acacia senegal* (Hashab), regenerates freely on cultivated lands, and when a piece of land is left fallow after cultivation, a gum garden forms (Jackson and Shawgi, 1950; Seifel Din, 1969). Hashab trees tend to last for about twenty years, during which, the soil regains its natural fertility. The cycle also provides year-round work for the farmer, keeping him engaged on his land during the dry season.

The *Acacia senegal* bush-fallow system is the most practical way of sustaining crop production on Kordofan's light sandy soils. Millet, sorghum, sesame, groundnuts, hibiscus, and watermelon are cropped for 3 to 5 years, until yield declines as fertility diminishes, or until cultivation becomes impossible under the dense crown of trees. The land is then left as bush-fallow, for fertility to be restored. These fallow areas, called "gum gardens", are utilized for gum arabic harvest, and cleared again in 10 to 17 years for cultivation.

The bush-fallow system of cultivation is a well-established, beneficial and sustainable farming system, particularly on the marginal land of Kordofan. It supports the livelihoods of local populations, since it is the major source of both cash and requirements for daily subsistence. Farmers have usually grown *Acacia senegal* trees along with agriculture crops (mainly sesame and groundnuts as cash crops, and millet and sorghum as subsistence crops). Gum arabic is, of course, the main product of *Acacia senegal,* and a universal cash crop. In addition, the trees provide the farmer with fuel wood for his own consumption, and for selling (Sharawi, 1986). *Acacia senegal* plays an important role in sustainable Agriculture & Forestry (Seifel Din, 1978).

As a result of the introduction of oil mills in the area, and the higher market value of oil relevant to gum arabic, farmers have shifted to the production of sesame and groundnut (oil cash crops) to secure more revenue. The repercussion has been a reduced area of *Acacia senegal*.

Consumption of woody forest products in the Gum Arabic Belt can clearly have significant impacts for the Kordofan Region, whether through loss of protection from desert encroachment, reduced fuel wood, reduced gum arabic resource, or, as is discussed here, reduced soil fertility. (See Tables 2.26 and 2.27).

2.4 Kordofan Agriculture & Forestry Production

Production of food and cash crops is very much dependent on the amount and distribution of rainfall. In the northern part of the region, total amount is critical, and in the South, distribution is most important. Located in the center of the country, Kordofan hosts a large variety of land use, climate and soil type. Sorghum and millet crops and the Gum Belt are selected as exposure units, as these represent the most important food and cash crops for the security of the large traditional rain fed Agriculture & Forestry sector.

2.4.1 Sorghum

Sorghum is the main staple feed crop in South Kordofan, and second in importance only to millet in North and West Kordofan. Its uses as food are diverse. Mainly the flour is used to make pancake (kisra), unleavened thick bread, porridge, or gruel. The sorghum plant is also a good feedstock to a number of different types of animals. It can be chopped for silage or fed directly to livestock. The sorghum grain can also be used as animal feed; the stover is often used as hay.

Sorghum is essentially a crop of the tropics and sub-tropics. It is adapted to high summer temperatures, particularly where soil moisture is adequate. The crop thrives well in the temperature range of 16° to 40° C, though its performance is optimized at a mean temperature of 27° C. It is suited to low/moderate rainfall; sorghum water requirements set the 500 mm-annual isohyte as its northern growing limit.

Nation-wide, sorghum is mainly produced in the rain fed sector, contributing about 80% of the country's total sorghum production. The irrigated sector's share is around 20% of the total. Sudan is self sufficient in sorghum production and is able to export some, in years of good production. In Kordofan, sorghum is cultivated in the southern and eastern parts of the region (the central clay plain), but may be cultivable in lowland parts of northern and central Kordofan. Information for crop yield of sorghum is available for a 26 year period (1971-1995). Historic sorghum yield is shown in Table (2.24).

2.4.2 Millet

Globally, millet is the fifth most important cereal crop for human consumption. It is the staple food crop for millions of people living in the semi-arid regions of Africa and South East Asia. About 14 million hectares are planted in both Africa and Asia.

Millet is the preferred staple food crop for the majority of the six million inhabitants of western Sudan (Kordofan and Darfur States). The average total area planted in millet each year, in the country as a whole, is about 2.1 million hectares. About 95% of this area is found in western Sudan. The grain is consumed as human food, mainly in the form of porridge, called "aseeda" or in the form of a thin pancake called "kisra". The stalks can be used as animal feed but they are primarily used as building material or fuel.

Millet is a hardy crop, capable of producing grain in regions of low soil fertility and limited moisture, where other summer cereals, like sorghum and maize, may fail. This is mainly due to its more extensive and efficient root system, as well as its ability to produce tillers. Although the crop is grown in areas where rainfall ranges between 200 mm to more than 1000 mm, most of its cultivation occurs in areas receiving between 250-700 mm. It does best in light, well-drained soil, and performs poorly in heavy clay soils, as it cannot tolerate water logging.

In Kordofan, most of the millet production is centered in the extensive sandy soils, which dominate the northern parts of the region. These are marginal areas, which receive less than 400mm of rainfall annually. In these areas, millet is the most extensively grown crop, and therefore, a millet-based farming system prevails. However, the cultivation of the crop extends further south into the clay soils, where rainfall goes up to 700 mm. Within these southern areas, sections of lighter, sandier soils are usually used for pearl millet. On average, the total annual area planted with pearl millet in Kordofan States is about one million hectares - over 90% of which, is found in North and West Kordofan States. Kordofan States plant about 45% of the total pearl millet acreage in Sudan. The crop is almost exclusively grown under traditional rained farming practices, using mainly local varieties. It is mainly consumed in Western Sudan, where the population is self sufficient in millet production. The grain yields obtained are very low - on average, below 200 kg/ha. Millet is the most important cereal crop in Kordofan, and is cultivated in most parts of the region. The information for crop yield of millet is also available for 1971 to 1995. (See Table 2.25).

2.4.3 Gum Arabic

Gum arabic, produced from *Acacia* s*enega*l and *Acacia seyal* trees, is considered one of the country's most important export crops. Sudan is the major producer and exporter of gum arabic, covering 80% of the outside world's needs. The product is used primarily in the food industry but has medicinal and technical uses as well.

Acacia senegal and *Acacia seyal* trees are grown in natural stands and also widely planted in the traditional rain fed sector, in a region known as the Gum Arabic Belt. Before the 1960s, gum arabic exploitation took place mainly within the Gum Belt zone, between latitudes 10° and 15° North. This zone covers an area of 520,000 km2 - equal to one fifth of the country's total area.

The Gum Belt protects and improves soils, thereby facilitating future agricultural cropping on depleted and fragile soils. To maintain soil fertility, farmers have for some time relied on Hashab trees as a rotation crop that naturally grows on fallow land (generally, farms which must be abandoned after five years of continuous cropping on sandy soils). Hashab trees generally last twenty years, during which the soil regains its natural fertility and farmers can begin cropping once more.

However, because of the droughts that have struck the country, the Gum Belt has shifted southward, to latitude 10° to 13° 45' North (IES 1990). Vegetation maps based on satellite imagery analysis also depict the southward shift of the Belt. The decline in vegetation cover has also been attributed to the expansion of mechanized farming, the absence of comprehensive planning for natural resources, rapid population growth, and the accompanying increase in demand for woody forest products.

2.5 Assessment Approach

Agriculture and forest products in Sudan are in a vulnerable position, even in the absence of climate change. Recent droughts, socioeconomic trends, and the on-going process of desertification have adversely affected the distribution and condition of both tree cover in the Gum Belt and agricultural crops in Kordofan, particularly in the sandy areas of North Kordofan and North Darfur. Increased human and livestock population and the lower than average rainfall over the recent dekads have led to widespread environmental degradation that is clearly reflected in production of the Agriculture & Forestry sector.

Under predicted conditions of climate change, crops and gum production will be further impacted, both directly, through changes in temperature and precipitation, and indirectly, through pests and diseases. Changes in climate are predicted to have a number of harmful impacts.

Overall objectives of the Agriculture & Forestry sector assessment for Kordofan Region are:
To identify and assess the potential impacts of climate variability and climate change on sorghum, millet, and gum arabic production;

To estimate the uncertainly surrounding these impacts;
To highlight the possible socioeconomic consequences of the climate impacts;
To identify the possible adaptive responses for reducing adverse effects.

Focusing on the first two objectives in this preliminary phase of activity, the impact assessment is undertaken by generating two types of climate scenarios (based on a doubling of CO2 by 2060, corresponding to 1% per annum increase of CO2 emissions), which are then used to gauge the sensitivity of the exposure units to climate change. This sensitivity is measured by comparing baseline scenarios (e.g., future crop yield, in the absence of climate change) to climate change scenarios (e.g., future crop yield under climate change conditions).

2.6 Study Area Description

The area selected for study is Kordofan Region, which is thought to be one of the most vulnerable areas in the country in the context of climate change. It is located in central Sudan between latitudes 9° 30’ and 16° 24’ North and longitudes 27° to 32° East. Kordofan, which lies largely within the arid zone, covers an area of about 382,316 km2, representing 24% of the total area of the country.

2.6.1 Geography

Administratively the study area consists of three states: North Kordofan, West Kordofan, and South Kordofan. The areas of these states are as showed in Table 2.3.

Table 2.3: Kordofan Characteristics

State	Area (square km)
North Kordofan	185,474
West Kordofan	111,164
South Kordofan	85,678
Total	**382,316**

Khartoum and the White Nile States bound Kordofan States from the East, Darfur States from the West, Upper Nile and Bahar El Gazal States from the South, and from the North, by Northern State.

2.6.2 Ecological Conditions

According to Harrison and Jackson, (1958) Kordofan is ecologically classified into the following five major zones: (1) Semi-desert (2) Low rainfall woodland savanna (3) High rainfall woodland savanna (4) Flood region and (5) Mountain vegetation. For the Agriculture & Forestry analysis, the latter two zones are grouped, and the Desert zone is added.

The semi-desert is sub-divided into 3 sub-zones *(i) Acacia tortilis* and *Maerua crassifolia* association *(ii)* Semi-desert-scrub on sand *(iii) Acacia mellifera-comiphora* desert scrub. The low rainfall woodland savanna is subdivided into *(i)* Low rainfall woodland savanna on sand *(ii)* Low rainfall woodland savanna on clay *(iii)* Special areas. Each of these sub-zones is comprised of several additional associations, named after the most dominant tree species and its associates.

According to these classifications, most of North Kordofan State and parts of West Kordofan State fall in the semi-desert zone. South Kordofan State and parts of West Kordofan are located in the woodland savanna zone (both low and high rainfall). The vegetation composition in this zone varies greatly corresponding mainly to soil type, texture and pattern of distribution of rainfall.

The region as a whole has diverse vegetation, resulting from the variability in soils and rainfall. In the North, low, desert and semi-desert scrub can be found. The sandy soils of the central area are covered with *Acacia senegal* savanna. The clay soils of South Kordofan are covered with broad-leafed savanna woodland (Acacia seyal and Balanites aegyptiaca).

The soil in Kordofan Region ranges from sandy in the North to heavy cracking clay in the Nuba Mountains plains of the South. Sixty percent of the cultivable area is sandy soil and 40% is clay. The sandy soil is stabilized by sand dunes locally known as "Goz". These consist of very deep, coarse to fine sand with low organic matter and a low cation exchange capacity. The clay soils are dark, cracking vertisols, low in nitrogen and phosphorus.

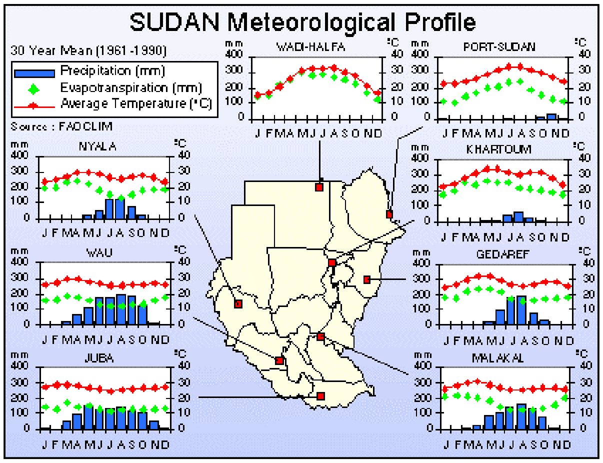
2.6.3 Meteorological conditions

The five major ecological zones of the region - Desert, Semi-Desert, Low-Rainfall Savannah, High-Rainfall Savannah, and Flood Plain/Montane Vegetation - are determined in large part by the climatic conditions. The distribution of these zones indicates that rainfall increases from North to South.

In Kordofan states, annual rainfall varies from 150 mm in the northern desert to about 850 mm in the South. The rainy season start between May and July, and extends into September or October. Average temperature ranges from 24° C to 28° C. Mean daily maximum temperature ranges from 32° C to 35° C, and the minimum ranges from 17° C to 21° C. (See maps in Section 4, Volume II).

Figure 2.1 illustrates the variability in Sudan's meteorological profile, with the northernmost areas receiving no measurable rain, and the southern areas receiving abundant rainfall throughout most of the year. In the center of the country, Kordofan experiences a combination of the extremes, with arid conditions mixing with rainfall that is historically adequate to support agriculture.

Figure 2.1: Meteorological Profile *(Source: FAO, 1997)*



Meteorological information for Kordofan was collected from the thirty-two climatic stations, distributed throughout the region. These can be classified as follows:

Rain gauges (27) measuring precipitation (P) in mm for 14 and 27 years.

Synoptic stations (4) with time series for precipitation (P) in mm and temperature (T) in degrees Celsius, for over 30 years. These stations are located in Kadugli (South), Rashad (East), En Nahud (West) and El Obied (North of center).

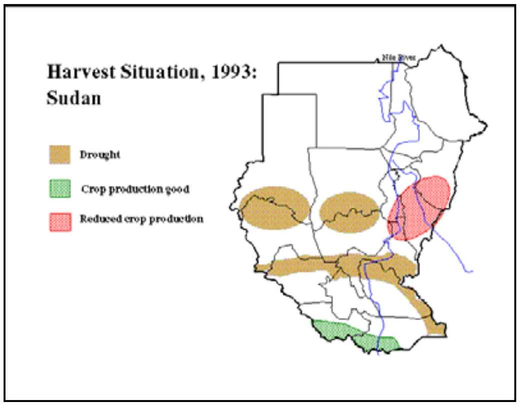
One synoptic station recording P in mm and T in degrees C for more than 14 years. This station is located in Babanusa (in the southwest part of the region).

Based on an analysis of these data, the annual range in temperature for Kordofan is between 20° and 43° C, and the range in precipitation is between 150 and 850 mm.

In the last 15 years, there has been an evident climatic shift, where rainfall is decreasing in both amount and distribution. Long dry spells during the rainy season have become frequent. Consequently, chances of crop failure have increased.

The study area, as well as other regions of Sudan, experienced six major droughts cycles in this past century (1933/39, 1951/53, 1968/73, 1984/85 and 1989/90) and numerous localized droughts. The image in Figure 2.2 outlines the parameters of the 1993 drought. Though sections of Kordofan were impacted by the drought, the damage to crops was felt most markedly in the eastern part of the country.

Figure 2.2: Sudan's 1993 Drought *(Source: USAID)*



Kordofan has been classified as severely to moderately affect by desertification in the northern parts and moderately to slightly affected in the South. Table 2.4 shows the risk classes, which are classified according to availability of vegetation cover, as follows:
Desert condition means 0% vegetation cover.
Very severe means 1% to 25% vegetation cover.
Severe means 26% to 50% vegetation cover.
Moderate means 51% to 75% vegetation cover.
Slight means 76% to 99% vegetation cover.
Very slight means 100% dense vegetation cover.

Table 2.4: Risk Classification of Kordofan

	Risk Class (square kilometers)						
State	Very Slight	Slight	Moderate	Severe	Very Severe	Desert	Total Area (sq km)
North Kordofan	2,101	1,618	64,69	9,805	24,211	143,161	185,474
South Kordofan	65,353	13,463	6,423	440	NA	NA	85,678
West Kordofan	48,308	19,557	16,010	9,815	9,473	8,002	111,164
Kordofan All	113,872	34,638	28,901	20,060	33,683	151,163	382,316

Source: NDDU (1998)

Both agricultural crops and the Gum Arabic Belt are sensitive to rainfall and to a great extent, temperature. Good rain years usually result in good production, and lack of rain is generally responsible for low production. Gum production is highly affected by late rain (during and after October) which can reduce both quantity and quality.

Changes in temperature will likely affect agricultural crops and gum arabic production as they may lead to changes in the planting dates of annual crops, and outbreaks of pests and pathogens. Low temperature at tapping time seems to seal off gum exudation points, so trees have to be retapped. On the other hand, higher temperature, when taken alone, appears to be conducive to gum production.

2.6.4 Socioeconomic situation

As shown in Table 2.5, the total population of the study area, as of 1998, was about 3.6 million. Kordofan is home to roughly 15% of the total population of Sudan. Its people tend to be rural, with the urban population constituting just 13%, nomads 24%, and fully 63% classified as sedentary rural.

Table 2.5: Population of Kordofan

State	Population
North Kordofan	1,437,677
West Kordofan	1,086,678
South Kordofan	1,080,678
Total	**3,605,033**

Source: Min. of Finance & National Economy & Statistical Bureau

2.7 Analytical Approach

A complete vulnerability and adaptation assessment requires a series of involved steps. In brief, these include:

Definition of the problem: In this case, vulnerability of the Agriculture & Forestry sector to climate change.

Selection of the Analytical Method: These can range from the qualitative (e.g. expert judgment) to the quantitative (e.g., impact modeling).

Method Testing: This step validates the approach, often against historical data, and is particularly important for predictive modeling tools.

Selection of Scenarios: Socioeconomic, environmental and climatological baseline scenarios, as well as climate change scenarios are generally used.

Impact Assessment: Baseline scenarios are measured against climate change scenarios, to provide a measure of impact.

Assess Adaptation Options: The ways in which a country might respond (locally, regionally, sectorally, and nationally) are considered, and the question of impacts revisited.

For the purposes of this analysis, the impacts of climate change on three specific exposure units, sorghum, millet, and gum arabic production - central components of the traditional rain fed Agriculture & Forestry sector - are the focus.

2.7.1 Available Methods

The following methods were selected for the purposes of the study:
Expert judgment,
Analogue (historical trends and spatial),
GIS techniques (for mapping and analysis of basic data on Kordofan states), and
Statistical methods (used to forecast crop yields and population growth).

2.7.2 Time frame

Historical trends: The selected time frame for historical data is 1961-1990 (an IPCC recommended normal period)

Baseline scenario: In keeping with the recommendation of the IPCC, a 30-year period is generally used.

Climatic scenario: The time horizon selected for projection of climate change scenarios differs from IPCC recommended time frames in that years 2030 and 2060 were selected as milestone years (in keeping with the adopted emissions scenario, IS92A). This is a departure from the IPCC proposed milestone years of 2015, 2050, and 2100.

2.7.3 Data Needs and Availability

The data required for agroclimatic zoning, crop yield, and gum arabic production are precipitation, temperature, soil characteristics and historical data for crop yield and gum arabic production.[2] The extreme northern parts of the region have no synoptic stations; accordingly, El Obied has been chosen to represent this area. The sources of the data are the Sudan Meteorological Authority, the Ministry of Agriculture and Forestry, the Department of Agricultural Statistics, and the Gum Arabic Company. The historic data for gum arabic production for the years 1961 through 1969 are not available. Thus, the study used available data (1970-1998) specifically that from 1970 to 1990, for time frame adjustment

General information for Kordofan States is available from a number of departments and organizations. Certain information (in maps and reports) is of good quality but needs to be updated. The primary sources of information are:
National Drought and Desertification Control Unit: Has vegetation, desert margin/classes, soils, ecological zones and rainfall maps.
Forests National Corporation: Has records on Gum area, distribution, yield, production. Management expertise is also available on different methods of forest management.
Ministry of Agriculture and Forestry's Department of Statistics: has time series of cereal and oil crops.
The Meteorological Department: Has good records on rainfall and temperature for the entire country, over more than forty years.
The Ministry of Finance's Department of Statistics produces a Census with population data.

2.8 Vulnerability Assessment

The steps undertaken in the vulnerability assessment are outlined in the sections below.

2.8.1 Definition of the problem

As identified in several of Sudan's national strategies, food security, and thus Agriculture & Forestry are a central concern for the nation. The precarious balance that exists between climate and agriculture and forestry production, in Kordofan (and in other parts of Sudan) made the potential impacts of climate change quite significant. As such this sector and region were identified as a priority area for vulnerability assessment. The sections below outline some of the baseline vulnerabilities of crop production and the threat posed by climate change.

Sorghum: Sorghum, a crop of the tropics and sub-tropics, is adapted to high summer temperatures, particularly where soil moisture is adequate. Though sorghum water requirements set the 500 mm annual isohyte as its northern growing limit, the recent repeated failure of millet has led farmers to expand cultivation of sorghum to isohyets lower than 400 mm. It is now grown in the low-lying areas and protected sandy soils of North and West Kordofan. Should areas currently under cultivation experience climatic shifts that decrease available moisture, sorghum production in Kordofan will be under serious threat. A summary of climatic requirements for sorghum appears in Table 2.6.

Table 2.6: Climatic requirements for sorghum

	Growing season

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[2] For calculation of potential evapotranspiration, data on sunshine hours, wind speed and water vapor pressure are also used.

Temperature Limits	Moisture Limits	Length/ Period
• Around 33° C • Optimal growth range (30 – 42° C)	• 400 – 800 mm/year • Under irrigation needs 6 - 8 waterings per year	• July/Aug – Dec/Jan • Growing season is normally 3-4 months

Millet: The droughts that have recently hit western Sudan, and the decrease in amount and duration of rainfall have resulted in frequent millet crop failures. The survival of local millet strains has been adversely affected, particularly the late-maturing varieties, potentially exposing subsequent crops to increased risk of failure.[3] These trends would be exacerbated by changes in temperature and precipitation, further challenging this stressed system of production. A summary of climatic requirements for millet appears in Table 2.7.

Table 2.7: Climatic requirements for millet

Temperature Limits	Moisture Limits	Growing season Length/ Period
• Optimal growth range (30 – 42° C)	• 400 – 800 mm/year	• Growing season is normally 3-4 months

Gum arabic: Gum arabic production in the country has declined from 29,145 metric tons in 1986/87 to 17,759 metric tonnes in 1996/97. In Kordofan, the production declined from 14,652 to 5,396 metric tonnes in the same period, according to data of the Gum Arabic Company. At the same time, the available analyses show an increase in the demand for woody forest products in general, for several different uses (mostly firewood and charcoal from Hashab trees) and an increase in the current trend of declining gum arabic area in Kordofan Region. Highlights of these trends are outlined below: (A summary of climatic requirements for gum arabic appears in Table 2.8.)

While in 1958, the southern limit of the Gum Belt was 15° N, today there is very little Hashab (Acacia Senegal) remaining north of latitude 13° 45' in Kordofan or Darfur. Areas immediately south of latitude 13° 45' have lost some 80% of the tree cover that existed in the early 1960s. The current distribution of Hashab in the Gum Belt is variable and patchy, depending on soil type, rainfall and human influence.

There has been a noticeable shift of gum arabic production southwards. As Hashab trees serve as the natural fertilizing agent in this region, the production of cereal crops in the North may be decreasing due to decreased forest area and lowered soil fertility. These trends depict a forest resource that is subject to multiple pressures: unsustainable human consumption, land degradation, and desertification. The impact of these pressures could be magnified by potential shifts in temperature and precipitation, further reducing gum arabic production and the services provided by the Gum Belt.

Table 2.8: Climatic requirements for gum arabic

Temperature Limits	Moisture Limits	Tapping season Length/ Period
• 35° - 42° C	• 250 – 350 mm/year	• October - April

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[3] During drought years, farmers lose seeds that would normally be kept for sowing. Following the drought of 1990-91, aid agencies resorted to importing bulk seed from abroad. Thus, the variety ‘Kano’ was imported from West Africa. Such bulk imports are capable of replacing or altering the genetic constitution of local strains, and might introduce susceptibility to disease and pests.

2.9 Selecting the Method

A series of analytical methods was assembled for the Agriculture & Forestry assessment. These are discussed in the following sections.

2.9.1 Tools for Assessing Crop Yield

FAOMET: This Food and Agricultural Organization model is used for computation of potential evapotranspiration (PET), an input to the impact model, FAOINDEX. PET, as defined by Penman, is the quantity of water evaporated and transpired by a short and uniform canopy of grass, for which there are no water constraints. The inputs are maximum and minimum temperature, sunshine hours, wind speed, and water vapor pressure. The data of the parameters are processed on a dekadal basis so as to accommodate the FAOMET model. Also the information of the geographical locations (longitude, latitude and altitude) for the selected stations is included. The output file of PET contains the geographical location information and the values of PET.

FAOINDEX: Also a Food and Agricultural Organization model, FAOINDEX is used for calculating the soil water balance. The input parameters are PET, precipitation, and a crop file. The contents of the crop file are soil water holding capacity, effective rainfall (in percentage, which depends on the elevation of the station), and finally, the crop planting dekad and cycle of the growth. The output parameters after running the model are the actual evapotranspiration, surplus/deficit of soil moisture, and water satisfaction index (WSI) in %, as well as a land range file.

Water Satisfaction Index (WSI): In the FAO's experience, a direct relationship exists between the cumulative water requirements of a crop - as measured by the water satisfaction index (WSI) - and final yield of the crop. As water is the primary limiting factor in crop production in Sudan, WSI offers a snapshot in time of an area's capacity to support a particular crop. The index can be used to provide estimates of crop yield, based on the degree to which a crop's water requirements were satisfied over the growing season. The WSI is a system by which water satisfaction conditions in an agroclimatic zone are measured against the optimal conditions (complete water satisfaction) for a given crop. The degree of to which a crop's water requirements are satisfied (i.e., WSI) is determined through the following process:
The FAOMET model is used for calculation of potential evapotranspiration (PET) from several inputs (temperature, vapor pressure, wind speed and sunshine hours), for a specific dekad.
WSI in the first dekad of the growing season is calculated as P1/PET1 (where P and PET are measured for the specific dekad).
WSI in the second dekad is (P1 + P2)/(PET1 + PET2).
Thus, the cumulative degree of water satisfaction for a crop over its entire growing season is calculated, beginning with the start of the crop cycle, and continuing by dekad, until crop maturity at the end of the growing season.

At the end of the growing season, the cumulative degree to which water requirements have been satisfied - measured as WSI - reflects the cumulative water stress endured by the crop, dekad after dekad. The higher the final WSI, the smaller the water stress is. The WSI values at the end of the growing season are closely linked to the final yield of crops and a qualitative indication of the crop condition during the growing season.

Agroclimatic zone classification system: There are many methodologies used for classifying areas into agroclimatic zones. The use of these depends on availability of data, geography of the location, and purpose of zoning. Some modifications and updating to the methodologies were applied in this study to provide results that suit the study area. Based on these criteria, the formula developed by Thornwaite is considered the most applicable for this inquiry. FAO, in 1972, used the same methodology (with some modifications) for classifying agroclimatic zones in India.

Based on Thornthwaite's 1955 system, the calculated moisture index for a given station is used to assign an agroclimatic zone classification to that station. This zone indicates the relative capacity of the area to support vegetation and crops. The cultivation of crops depends on the type of climate, (i.e., on the agroclimatic zone). Millet crop grows in the semi-arid zones and if this should shift toward arid zone, the risk of crop failure increases. On the other hand, if humid agroclimatic zones shift northward in the region, the cultivation of sorghum and other crops could be encouraged. Accordingly, predictions of the distribution of agroclimatic zones in the future, is a necessary tool and reference point for scientists, policy-makers and stakeholders. These zones, as identified by Thornthwaite, are shown in Table 2.9.

The formula that Thornthwaite (1955) used for agroclimatic classification is as follows:
$I_m = I_h - I_a = 100 * (P/PET - 1)$
Where,
I_m =Moisture index
I_h = Humidity index
PET = Potential Evapotranspiration in mm
P = Precipitation in mm If $P>PET$, surplus water exists; if $P<PET$, a water deficit exists.
I_a = Aridity index

Table 2.9: Classification of agroclimatic zones using moisture index

Class type	CLIMATE TYPE	MOISTURE INDEX *(I_m)*
A	Per-humid	100 or above
B4	Humid	80 to 100
B3	Humid	60 to 80
B2	Humid	40 to 60
B1	Humid	20 to 40
C2	Moist sub-humid	0 to 20
C1	Dry sub-humid	-33.3 to 0
D	Semi Arid	-66.7 to -33.3
E	Arid	-100 to -66.7

Moisture Index: Using PET, and several sets of climate data, a moisture index is assembled, according to Thornthwaite's formula. I_m is taken as an average at the climate station, and is used to establish agroclimatic zones. The moisture index (I_m) is adjusted according to the growing season, starting from the dekad where effective precipitation was reported as a sign for sowing. The growing season in the region generally extends from June to September. The average of the measured moisture indices for this four-month period determines the agroclimatic zone classification.

2.9.2 Tools for Assessing Gum Arabic Production

Given the distinct characteristics of the gum arabic crop, assessing its production involves a somewhat modified approach. The estimation of gum arabic production depends on the water satisfaction index of the post-rainy season, and on residual moisture in the soil. The rainy season in the region extends from June to October. The water satisfaction index in the last dekad of October month indicates the condition of the Hashab trees for gum arabic production in the dry season. The tapping of Hashab trees begins in the last dekad of October. The growing season for Hashab trees differs from planted crops, which depend on the date of effective rain to assign the date of sowing. Temperature, as well as rainfall, plays a vital role in production. High temperatures during October through April are favorable, and encourage high production of gum arabic.

After running the soil water balance model, a file is created of the water satisfaction index of green cover land range (the area, which includes Hashab trees and is thought to largely exclude cultivated crops). The WSI is then validated against the historical data of gum arabic production. However, in the case of Kordofan Region, area of production is unavailable, preventing yield calculations. Thus, it is not possible to adequately test the WSI ability to predict gum arabic yield. The WSI baseline for the region is used as an average water satisfaction index for the five selected stations.

The area of Hashab trees in Kordofan varies between 1.25 to 1.8 million hectares with an average of 1.51 million hectare and the density of trees varies between 120 to 300 trees per hectare with an average of 210 trees per hectare. The available historical data of gum arabic production extends to from 1969 to 1997. The period from 1967 to 1990 was used for validation. The best three seasons of the highest production were 1970/1971 (22198 tonnes), 1974/1975 (27328 tonnes) and 1975/1976 (24274 tonnes). The average of the best three production values is 26,600 tonnes. The best gum arabic yield is 16.1 kg/ha which corresponds to a value of 33 % of WSI at the last dekad of October. The estimation of the future gum arabic yield, the WSI was obtained in milestone years 2030 and 2060 in the five selected stations. The average value of WSI for Kordofan Region was obtained from the five values. From the table shown below the gum arabic yield was obtained. The WSI gum arabic values were obtained from a land range file which refers to any green cover, including Hashab trees. This land range file is generated during running soil water balance model. The Hashab tree yield varies between 0.052 to 0.130 kg/tree. The table below shows the validation of gum arabic yield against the WSI.

2.10 Testing the Method

2.10.1 Crop Yield Assessment Tools

In the light of FAO's experience that a direct relationship exists between the cumulative Water requirements Satisfaction Index (WSI) and the final yield of the crop, this yield can be expressed either in absolute figures (kg/ha) or in relative figures (% of an optimum crop). Using the historical data for Kordofan Region, a crop yield scale had been constructed for both sorghum and millet crops (as shown in Section 2.17, Tables 2.28 and 2.29).

To validate the WSI approach, WSI values were back-casted using historic temperature and precipitation data. From these values, associated crop yield values were generated for comparison against actual historic yield data (for both sorghum and millet). These values are generated using the FAO scale for sorghum and millet crops. To arrive at this comparison, the following steps are taken:

First, a maximum potential yield is established as an average of the three best yields. This yield is associated with optimal water satisfaction requirements (the scale showing the relationship between the percentage satisfaction of water requirement and the percentage of maximum foreseeable yield is shown in Table 2.10).

Table 2.10: FAO scale for crop yield estimation from water satisfaction index

Yield relative to average of 3 best yields	>100%	90-100%	50-90%	20-50%	10-20%	Complete Failure
FAO SCALE Quality	Very good	Good	Average	Mediocre	Poor	< 50
WSI (%)	100%	95-99	80-94	60-79	50-59	0

Second, the maximum crop yield (MAXYLD) is obtained from averaging the 3 best crop yield years.

Third, this maximum crop yield (MAXYLD) is considered 100% of the possible crop yield. From the FAO scale, the percentage associated with MAXYLD (100%) is associated with a value of WSI. Specific crop yield values are generated by identifying the percentage yield associated with back-casted values of WSI. In other words, if historic temperature and precipitation data for year X generate a WSI of 99, according to the FAO scale, the associated crop yield is 100% of maximum yield. Thus in year X, this method predicts that crop yield was equivalent to the maximum yield. This prediction is tested against the actual yield for year X to determine the fitness of the method.

To give an example, consider sorghum**:**

If Maximum Yield for sorghum (average of the best 3 yields) = 748 kg/ha then:
Crop yield at 100% of Maximum Yield (corresponding to WSI = 99) = 748 kg/ha
Crop yield at 50% of Maximum Yield (corresponding to WSI = 80) = (.5*748) = 374 kg/ha
Crop yield at 10% Maximum Yield (corresponding to WSI = 50) = (.1*748) = 75 kg/ha.

Steps must be taken to adjust the two scales (crop yield and WSI) to one another to allow for precise validation of WSI against historical data. For example, for a crop yield of 90 to 100%, the corresponding range of WSI is 95 to 99 (according to FAO), but in order to move along the WSI Index, or along the range of crop yield, values of individual corresponding increments must be determined. This is done as follows:
The crop yield values for 90% to 100% are 673 to 748 673 kg/ha – a range of 75 kg/ha.
The WSI for this range is 95 to 99 – a range of four.
To determine the crop yield value of one WSI increment in this range, 75 kg/ha is divided by four WSI units.
One WSI increment in the 95-99 range, then, corresponds to 18kg/ha.

Using another example:
The crop yield values for the 50% to 90% of maximum yield are 397 to 673 kg/ha (a range of 272).
The WSI values are 80 to 94 (a range of 14).
Thus, one WSI increment corresponds to 19 kg/ha (272 divided by 14).

Using these steps, gaps can be filled between the major levels, allowing for more precise estimates of historic crop yield. However, care should be taken, as this treatment differs from range to range and from crop to crop.

Table 2.11: Scale for estimation of gum Arabic yield relative to WSI in Kordofan Region

Crop yield (%)	WSI (%)	Gum Arabic yield (kg/ha)	Crop yield (%)	WSI (%)	Gum Arabic yield (kg/ha)
100	>33	> 16.1	51	17	8.2
99	33	16.1	47	16	7.6
96	32	15.5	46	15	7.4
93	31	15.0	43	14	6.9
90	30	14.5	40	13	6.4
87	29	14.0	37	12	6.0
84	28	13.5	34	11	5.4
81	27	13.0	31	10	4.9
78	26	12.5	28	9	6.1
75	25	12.1	25	8	4.4
72	24	11.6	22	7	3.8
69	23	11.1	19	6	3.4
66	22	10.6	16	5	2.6
63	21	10.1	13	4	2.1
60	20	9.7	10	3	1.6
57	19	9.2	7	2	1.1
54	18	8.7	4	1	< .6

2.10.2 Gum Arabic Assessment Tools

To validate the selected method for gum arabic production, the following steps are taken: Again, the maximum gum arabic yield (x) is obtained from each of the three best gum arabic yield years. The average is then taken from these three values. This maximum gum arabic yield (x) is taken as 100% of possible yield. The average WSI of the three best yields at the last dekad of October is obtained and is found to be 33%. Thus, gum arabic yield at 100% is assumed to correspond to a WSI of 33.

The same steps outlined above are taken to fill gaps between yield ranges.

If the maximum gum arabic yield is 16.1 kg/ha, then:

Gum arabic at 100% of Maximum Yield (corresponding to WSI = 33 %)

Yield = 16.1 kg/ha

Gum arabic at 81% of Maximum Yield (corresponding to WSI = 27%)

Yield will = .81*16.1 kg/ha = 13 kg/ha

Gum arabic yield at 51% of Maximum Yield (corresponding to WSI 17 %)

Yield will be .51* 16.1 = 8.2 kg/ha.

2.11 Fitness of Method for Assessing of Crop Yield and Gum Arabic Production

The yield values generated above for sorghum, millet and gum arabic were compared with the historical data from selected test years, to explore the fitness of this method in estimating Kordofan's Agriculture & Forestry production. The following results were obtained for Kordofan Region as a whole.

Validation 1974:
Millet: (average yield/historic yield)*100 = (132/236)*100 = 56%
Sorghum: (average yield/historic yield)*100 = (573/643)*100 = 89%

Table 2.12: Test Year: 1974 (for Kordofan Region)

Crop	Average WSI (%)	Average Yield (kg/Ha)	Historic Yield (Kg/Ha)
Millet	67	132	236
Sorghum	90	573	643
Gum Arabic	10	3,697 to 9,839	9,839

Validation 1984:
Millet: (average yield/historic yield)*100 = (<43/36)*100 = 100%
Sorghum: (average yield/historic yield)*100 = (310/174)*100 > 100%

For millet crop, both values for average and historic yields are referring to a complete failure of the season 1984.

Table 2.13: Test Year: 1984 (for Kordofan Region)

Crop	Average WSI (%)	Average Yield (kg/Ha)	Historic Yield (Kg/Ha)
Millet	46	<43	35
Sorghum	74	310	174
Gum Arabic	10	3,697 to 9,839	9,839

Validation 1988:
Millet: (average yield/historic yield)*100 = (165/173)*100 = 95%
Sorghum: (average yield/historic yield)*100 = (612/527)*100 > 100%

Table 2.14: Test Year: 1988 (for Kordofan Region)

Crop	Average WSI (%)	Average Yield (kg/Ha)	Historic Yield (Kg/Ha)
Millet	72	165	173
Sorghum	92	612	572
Gum Arabic	10	3,697 to 9,839	9,839

The fitness of the test data with the historical data is considered reasonable. The method is a better fit to sorghum crops than to millet. This may be attributed to the actual area of millet production being inaccurately represented, due to the lack of data in the northern parts of the region, and accordingly represented by El Obeid station.

2.12 Limitations and Uncertainties

Of the three yields, gum arabic is particularly difficult to forecast. The climatic, socioeconomic, and environmental variables influencing the production of gum arabic are undoubtedly correlated, but unambiguous correlation coefficients have not been determined. Thus, production cannot be made the subject of a reasonably reliable long-term projection. At present, the forecasting of gum arabic production remains largely a matter of expert judgment as to changes in the variables.

Relying on such judgment, a system for forecasting yearly production of gum arabic needs to take into account following assumptions and limitations:
The methodology of the FAO scale has been utilized for the estimation of gum arabic yield, as described above. One of the key limitations in this approach is the adjustment of the scale. Maximum crop yield (100%) generally corresponds to WSI of close to 100, while for gum arabic yield, maximum crop yield (100%) corresponds to WSI of 33 at the end of October. At this phase in analysis, this discrepancy is not fully accounted for.
There are no annual figures for area and density of Hashab trees. The available data are in ranges. According to expert advice, the analysis used available averages for both area of production and density of trees per hectare.
Farmers' decisions as to how many hectares will be tapped vary year to year, mainly according to the results of field crop yields and gum arabic prices.
It is assumed that farmers annually tap about 200 trees. This is based on the assumption that farmers generally tap within the same area every year, and that these areas have a relatively constant number of trees.
The yield per tree is considered a constant 25 kg/tree. However, annual yield of gum is known to vary significantly from one tree to another. The figure used here, derived from gum arabic research, is considered realistic; this figure is used in the study.
Rainfall is known to be a key determinant of gum yield. Estimates of the direct influence of annual rainfall on gum yield need to be obtained by comparing historic gum production with the corresponding rainfall data. However, in this phase of activity, the exact correlation is not known.
It is assumed that tapping is carried out in the month of October.
Deforestation, desertification, and land degradation are having a significant impact on distribution and amount of Hashab forest. The socioeconomic and environmental pressures exerted on this resource are not currently accounted for.

2.13 Selecting Scenarios

In order to measure the sensitivity of Agriculture & Forestry production to climate change, it is necessary to create future Agriculture & Forestry production scenarios that might occur, in the absence of climate change. These are the study's baseline scenarios. These are measured against parallel climate change scenarios (i.e., production scenarios that would occur in the *presence* of climate change) through which the sensitivity of Agriculture & Forestry production to climate change can be assessed.

In subsequent analyses, it will be important that additional variables be incorporated into the scenarios. The most comprehensive approach to gauging the sensitivity of a sector involves the development of scenarios that internalize future environmental, socioeconomic conditions, as well as climatic conditions. For this first phase of activity, this study has focused effort on creating these baseline scenarios of climate and Agriculture & Forestry production, and has not yet integrated projections of environmental and socioeconomic changes into the assessment. This is identified as an area of future effort.

The following sections provide an overview of the input to baseline and climate change scenarios.

2.13.1 Baseline Scenario

Baseline scenarios have been calculated for Kordofan's agroclimatic zones, and thus, crop yield and gum arabic production, using an FAO soil/water balance model, and gauging the results relative to a Water Satisfaction Index (WSI). These are considered the state of reference for climate change projections. The comparison of baseline production scenarios and production scenarios generated under climate change conditions will help to establish the level of vulnerability of the Agriculture & Forestry sector, and to assign a degree of sensitivity and level of risk.

The agroclimatic baseline scenario is a tool used to identify crop and vegetation zones under natural climate conditions/variations. These baselines are then used to identify changes in zones under conditions of climate change, for the periods defined by the IPCC. In this study, the baseline scenarios are constructed for the five selected stations in the region and for each of the Agriculture & Forestry crops of interest. The sections below outline the current/historic patterns in production and the baseline projections of production.

2.13.2 Climate Change Scenarios

Two distinct approaches have been applied to the development of climate change scenarios. The first, Approach One, relies on General Circulation Models (HADCM2, BMRC, and GFDL) and climate scenario generating software (MAGICC/SCENGEN v. 2.4). The second, Approach Two, 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. (For a detailed description of climate scenarios, see Chapter 3 of Volume I, section 2).

Temperature and precipitation values from each of these approaches were used in the soil/water balance model to determine WSI and crop yield. The resulting patterns are described in the following section.

2.14 Impact Assessment

2.14.1 Results of Approach One: GCM climate change scenarios

The predicted values of mean temperature and precipitation for the three models are divided on a dekadal basis so as to accommodate the impact models used in this study. Since the parameters (moisture index, water satisfaction index, and crop yield and gum arabic production) reflect the impacts of climate change on the Agriculture & Forestry sector, they are used as exposure units. The impacts of the projected temperature and precipitation on these exposure units are summarized as follows:

Agroclimatic Zones (Moisture Index): The moisture indices for the baseline (1961-1990) (which was taken as the baseline for both milestone years 2030 and 2060), varies in the five stations between -13 and - 57. In milestone years 2030 and 2060, the moisture indices derived from the three GCM models, are below baseline, and range between -19 and -66 in the five stations. The exception is Rashad station, where the moisture indices in milestone years 2030 and 2060 are about the baseline.

Water Satisfaction Index (WSI): Projected values of water satisfaction index generated by applying climate change values of precipitation and temperature to the soil water balance model, are found to be below baseline in milestone years 2030 and 2060.

In El Obeid, En Nahud, and Babanusa, the poor values of WSI indicate a high level of risk for both sorghum and millet cultivation. The situation in Kadugli is somewhat better than these three stations, due to its location in the humid southern part of the region.

Again the exception is Rashad where the values of WSI are near baseline. The elevation of Rashad is about 800 meters above sea level, which affects the variation in temperature.

Crop Yield: From the milestone year values of water satisfaction for the five stations, the quality of growth for both millet and sorghum was found to be declining (except in Rashad and Kadugli). Crop yield for both sorghum and millet reported a decline in the three models. The decline in sorghum yield varies between 13% and 82% in milestone years 2030 and 2060 relative to the baseline. For millet crop the decline varies between 20% and 76% in both milestone years, except in El Obeid station, where complete failure is reported (<43 kg/ha in both milestone years).

As would be expected, the exception is Rashad and, to a lesser extent, Kadugli, where the predicted crop yields were about the baseline. The input parameters' (T, P & WSI), tables and the output parameter (crop yield) tables are referred to in Tables 2.15 through 2.20.

Table 2.15: Average sorghum yield in the baseline (1961-1990)

Station	Temperature (˚C)	Precipitation (mm)	I_m (%)	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 2.16: Projected sorghum yield in 2030

Station	Temperature (˚C)	Precipitation (mm)	I_m (%)	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 2.17: Projected sorghum yield in 2060

	Temperature	Precipitation	I_m	WSI	Crop yield

Station	(˚C)	(mm)	(%)	(%)	(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

Table 2.18: Average millet yield in the baseline (1961-1990)

Station	Temperature (˚C)	Precipitation (mm)	I_m (%)	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 2.19 Projected millet yield in 2030

Station	Temperature (˚C)	Precipitation (mm)	I_m (%)	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 2.20: Projected millet yield in 2060

Station	Temperature (˚C)	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

Both sorghum and millet crops are projected to drop under conditions of climate change. Yields decline from baseline in year 2030 and drop further in 2060.

Gum Arabic Production: Based on the projected values of water satisfaction, the corresponding regional gum arabic production is expected to drop below baseline in milestone years 2030 and 2060.[4] The baseline moisture index established for Hashab trees varies between -19 and -72. From the results of the three models, the values in milestone years drop to between -30 and -76. These values of moisture satisfaction are likely to cause growth retardation in the gum arabic

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[4] Production of gum arabic is measured on a region-wide basis, since gum arabic yield in the stations was found to poorly reflect the area and density of trees.

trees. This can occur despite the fact that rainfall may remain near – or even above – baseline levels, since an accompanying rise in temperature can lead to higher evaporation.

2.14.2 Results of Approach Two: Synthetic climate change scenarios

Using synthetic (incremental) climate change scenarios, the study finds that crop yields for both millet and sorghum drop below baseline and show a general declining trend. The exception to this trend is seen in cases of significant precipitation increase (i.e., 20%) It is assumed that such a dramatic increase in precipitation could adequately moderate the influence of temperature and evaporation. 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.

The rise in temperature during the growing season is very significant since an increment of 1.5˚ means that an additional 180˚C (1.5 C*120 days, taken at the last dekad), is endured by the crop over the growing season. This is considered to be too great an increase for the crop to fully adapt to. This results in a significant difference between the baseline crop yield scenario and the synthetic scenario's crop yield at the first increment.

The impacts on the targeted exposure units of incremental changes in the two parameters are discussed below.

2.14.3 Agroclimatic Zones

The values of moisture indices (I_m) for agroclimatic classification (Table 2.33) decrease in most scenarios, thus, the arid zone would extend to the South in most scenarios. Exceptions are in cases where the temperature changes from 1.5º to 3.5º C while precipitation increases by 20%. In this case, the moisture index is reported to rise in the eastern parts of the region, represented by station Rashad.

2.14.4 Water Satisfaction Index (WSI)

The impacts derived from the scenarios reported an overall decrease in water satisfaction for both sorghum and millet crops. In the eastern areas (represented by Rashad), the WSI remains near baseline at increments of temperature 1.5º and 2.5º C and a rise of 20% in precipitation. WSI shows a decrease with a rise in temperature from 3.5º to 4.5º C. In the case of Kadugli, WSI shows a decrease relative to the baseline in all four increments of temperature.

In scenarios where the increment of precipitation ranges from 10% to 20% and the increment in temperature, from 1.5º to 2.5ºC, the values of WSI are close to baseline - a pattern attributed to the effect of significant rainfall. When the increment of temperature exceeds 2.5º C, the WSI values drops (the results are presented in Section 2.17, Tables 2.34 and 2.35).

2.14.5 Crop Yield

As is expected from declining WSI, crop yield in most scenarios is found to be below the baseline scenarios (see Section 2.17, Tables 2.39 and 2.40). The general trend is of declining yields, except in the eastern parts of the region (represented by Rashad station), again, in cases where temperature increase is moderated by dramatic (20%) increases in precipitation. A decline again takes place in the cases where temperature increases by 3.5º or 4.5º C. However, even these decreases remain near the baseline.

The situation in Rashad can be interpreted as the moderating affect of altitude on high temperatures. The relatively good crop yield seem in Kadugli can be attributed the location of the station in the moist sub-humid zone. The most vulnerable areas in the region are found to be the northern, western, and southwestern parts of the region, which are very sensitive to increases in temperature.

2.14.6 Gum Arabic Production

The water satisfaction indices for Hashab trees in Kordofan Region are validated against the historical data of gum arabic production. From the results obtained in the twenty scenarios, WSI in the north, west and southwest of the region is below the baseline, and at each of these stations, gum arabic yield drops to between 4.0 to 10.5 kg/ha – a decrease of between 25% and 30 %.

In the scenarios where precipitation increases by 10% to 20% relative to the baseline, high values of water satisfaction appear to be reached. Rainfall is thought to be the factor that predominately controls the productivity of Hashab trees. However, the systematic rise in temperature, assumed throughout the whole year, will increase the rate of evaporation, hence, the available water is not anticipated to be fully utilized by Hashab trees. Consequently, production is predicted to decrease significantly in the north, west and southwest of the region. In scenarios where rising temperature and declining precipitation come together, a decline in production will be more significant.

In contrast to El Obeid, En Nahud, and Babanusa, the yield in Rashad and Kadugli is maintained near baseline level - a good indication for Hashab trees in these areas.

2.15 Discussion

In the extreme northern parts of the region, climate data are unavailable. Thus it is not presently possible to extend our study to that very vulnerable area of the region.

In most parts of Kordofan, the historical data for crops and gum arabic production are incomplete. Thus it is not possible to harmonize the baseline scenario with the time frames suggested by IPCC.

The availability of data for generating environment and socioeconomic baseline scenarios is another significant limitation.

2.16 Conclusions

The findings of this impact assessment suggest that the Agriculture & Forestry sector in Kordofan Region is very vulnerable to the impacts of climate change. The vast majority of people in the region still depend on traditional rain fed farming. The temporal and spatial variation of rainfall still determines activities and development in the region.

The rise in temperature reported in the projections of all three models - without a single decline - is a threatening finding. The projected temperatures could increase the rate of evaporation, reduce water satisfaction, and increase crop stress and crop failure.

The projections for milestone year 2030 and 2060 show a crop yield decline of between 15% and 62% for millet, 29% and 71% for sorghum, and 25 and 30% for gum arabic, with reference to the baseline.

The results of crop yield impact projections present a very serious picture to scientists, policy makers, and stakeholders. These actors must join forces in the design of integrated, practical responses to this threat for the sake of future generations.

2.17 Additional Tables

Tables 2.21 through 2.44 provide additional details regarding production characteristics of sorghum, millet, and gum arabic.

Table 2.21: Area and Production for sorghum (1970 - 1999) in Kordofan compared to Sudan

	Sudan		Kordofan			
Season	Area (E3 ha)	Production (E6 tonnes)	Area (E3 ha)	Production (E6 tonnes)	Area Share	Production Share
70/71	2,056	1,535	393	234	19%	15%
71/72	1,912	1,592	281	246	15%	15%
72/73	1,720	1,301	440	228	26%	18%
73/74	2,373	1,691	506	240	21%	14%
74/75	2,343	1,792	411	264	18%	15%
75/76	2,734	2,143	372	225	14%	10%
76/77	2,813	2,606	574	414	20%	16%
77/78	2,887	2,082	524	359	18%	17%
78/79	2,902	2,353	511	394	18%	17%
79/80	2,332	1,461	378	156	16%	11%
80/81	2,927	2,084	452	296	15%	14%
81/82	3,913	3,335	454	294	12%	9%
82/83	3,564	1,884	572	323	16%	17%
83/84	3,690	2,006	550	167	15%	8%
84/85	3,356	1,097	488	85	15%	8%
85/86	5,527	3,597	682	342	12%	10%
86/87	4,960	3,277	584	225	12%	7%
87/88	3,390	1,363	278	114	8%	8%
88/89	5,579	4,425	702	438	13%	10%
89/90	3,802	1,536	347	105	9%	7%
90/91	2,760	1,180	226	38	8%	3%
91/92	5,101	5,581	420	165	8%	3%
92/93	6,200	4,042	566	332	9%	8%
93/94	4,586	2,386	538	141	12%	6%
94/95	6,430	3,648	981	366	15%	10%
95/96	5,045	2,450	559	115	11%	5%
96/97	6,556	4,179	1,034	185	16%	4%
97/98	5,311	2,871	751	278	14%	10%
98/99	6,310	4,156	729	252	12%	6%

Table 2.22: Area and Production for millet (1970 - 1999) in Kordofan compared to Sudan

	Sudan		Kordofan			
Season	Area (E3 ha)	Production (E6 tonnes)	Area (E3 ha)	Production (E6 tonnes)	Area Share	Production Share
70/71	729	439	315	148	43%	34%
71/72	873	441	499	195	57%	44%
72/73	1,112	355	669	113	60%	32%
73/74	1,140	285	729	116	64%	41%
74/75	1,085	403	556	131	51%	33%
75/76	1,129	388	543	135	48%	35%
76/77	1,127	449	533	185	47%	41%
77/78	1,282	500	520	169	41%	34%
78/79	1,299	553	542	219	42%	40%
79/80	974	309	354	100	36%	32%
80/81	1,091	491	395	169	36%	34%
81/82	1,228	509	526	145	43%	28%
82/83	999	227	355	73	36%	32%
83/84	1,271	314	524	76	41%	24%
84/85	1,439	168	665	24	46%	14%
85/86	1,725	417	890	162	52%	39%
86/87	1,544	285	724	109	47%	38%
87/88	1,096	153	500	73	46%	48%
88/89	2,385	495	1,593	275	67%	56%
89/90	1,559	161	973	85	62%	53%
90/91	662	85	328	25	50%	29%
91/92	1,118	308	399	36	36%	12%
92/93	1,558	449	449	53	29%	12%
93/94	1,069	221	449	35	42%	16%
94/95	3,237	973	1,694	415	52%	43%
95/96	2,418	385	1,033	41	43%	11%
96/97	1,634	440	2,047	112	125%	25%
97/98	2,809	643	2,161	312	77%	49%
98/99	2,762	670	175	138	6%	21%

Table 2.23: Production for gum arabic (1969 - 1997) in Kordofan compared to Sudan

	Production (E6 tonnes)		
Season	Sudan	Kordofan	Share (%)
1969/70	35,063	20,774	59%
1970/71	38,616	22,198	57%
1971/72	31,468	16,815	53%
1972/73	25,940	12,685	49%
1973/74	23,464	10,902	46%
1974/75	46,500	27,328	59%
1975/76	43,000	24,274	56%
1976/77	32,141	17,897	56%
1977/78	32,200	18,350	57%
1978/79	26,287	13,994	53%
1979/80	20,699	11,881	57%
1980/81	24,367	13,425	55%
1981/82	31,984	17,523	55%
1982/83	22,555	12,881	57%
1983/84	34,000	18,461	54%
1984/85	11,313	6,335	56%
1985/86	18,047	10,310	57%
1986/87	25,268	14,652	58%
1987/88	20,000	11,820	59%
1988/89	24,256	14,500	60%
1989/90	22,408	13,440	60%
1990/91	11,786	5,062	43%
1991/92	7,439	5,715	77%
1992/93	11,410	3,697	32%
1993/94	22,178	5,396	24%
1994/95	39,303	17,151	44%
1995/96	30,291	13,397	44%
1996/97	17,746	8,215	46%

Table 2.24: Area, production and yield for sorghum (1970 - 2000) in Kordofan

Season	Area (E3 ha)	Production (E3 tonnes)	Yield (kg/ha)
70/71	395	234	592
71/72	282	246	871
72/73	442	228	516
73/74	508	240	472
74/75	413	264	640
75/76	374	225	601
76/77	577	414	718
77/78	527	359	681
78/79	514	394	767
79/80	380	156	410
80/81	454	269	592
81/82	456	294	644
82/83	575	323	562
83/84	553	167	302
84/85	490	85	173
85/86	686	342	499
86/87	587	225	383
87/88	280	114	407
88/89	706	438	621
89/90	349	105	301
90/91	227	38	167
91/92	422	165	391
92/93	569	332	584
93/94	541	141	261
94/95	986	366	371
95/96	562	115	205
96/97	1,039	185	178
97/98	755	278	368
98/99	732	252	344
99\00	700	195	279

Table 2.25: Area, production and yield for millet (1970 - 1998) in Kordofan

Season	Area (E3 ha)	Production (E3 tonnes)	Yield (kg/ha)
70/71	315	148	470
71/72	499	195	391
72/73	669	113	169
73/74	729	116	159
74/75	556	131	236
75/76	543	135	249
76/77	533	185	347
77/78	520	169	325
78/79	542	219	404
79/80	354	100	282
80/81	395	169	428
81/82	526	145	276
82/83	355	73	206
83/84	524	76	145
84/85	665	24	36
85/86	890	162	182
86/87	724	109	151
87/88	500	73	146
88/89	1593	275	173
89/90	973	85	87
90/91	328	25	76
91/92	399	36	90
92/93	449	35	78
93/94	1694	415	245
94/95	1033	41	40
95/96	2047	112	55
96/97	2161	312	144
97/98	175	138	789

Source: Min. of Agriculture & Forestry, Dep. Agricultural Statistics

Table 2.26: Production of gum arabic (1969 - 1997) in Kordofan

Season	Production (tonnes)
1969/70	20,774
1970/71	22,198
1971/72	16,815
1972/73	12,685
1973/74	10,902
974/75	27,328
1975/76	24,274
1976/77	17,897
1977/78	18,350
1978/79	13,994
1979/80	11,881
1980/81	13,425
1981/82	17,523
1982/83	12,881
1983/84	18,461
1984/85	6,335
1985/86	10,310
1986/87	14,652
1987/88	11,820
1988/89	14,500
1989/90	13,440
1990/91	5,062
1991/92	5,715
1992/93	3,697
1993/94	5,396
1994/95	17,151
1995/96	13,397
1996/97	8,215

Source: Min. of Agriculture & Forestry, Dep. Agricultural Statistics

Table 2.27: Forestry products demand forecast for Kordofan (cubic meter per year)

Year	Dukhan	Furniture	Construction	Charcoal	Firewood
1993	35,659	26,994	193,213	539,212	1,064,405
1994	37,070	27,334	196,121	546,201	1,076,043
1995	38,528	27,813	199,969	553,611	1,086,023
1996	40,216	28,214	203,324	560,849	1,094,082
1997	41,959	28,620	206,717	56,821	1,104,858
1998	43,508	29,029	210,148	576,007	1,115,014
1999	45,427	29,433	213,618	583,597	1,125,911
2000	47,084	29,858	217,124	591,289	1,136,850
2001	49,058	30,277	220,668	598,733	1,144,109
2002	50,891	30,699	224,249	606,956	1,151,977
2003	52,990	31,125	227,865	614,561	1,158,935
2004	54,871	31,553	231,517	622,961	1,169,643
2005	56,879	31,985	235,204	630,698	1,176,279
2006	59,170	32,420	238,926	638,871	1,183,502
2007	61,228	32,858	242,682	647,098	1,189,664
2008	63,428	33,299	246,472	655,389	1,196,404
2009	65,602	33,743	250,295	663,719	1,202,005
2010	68,162	34,230	254,152	672,088	1,208,175
2011	60,552	34,638	258,042	680,918	1,213,127
2012	72,925	35,090	261,964	689,366	1,221,426
2013	75,362	35,545	265,919	698,269	1,226,645
2014	77,950	36,002	269,905	706,763	1,227,623
2015	80,520	36,463	273,923	725,729	1,233,973

Source: Forest survey papers 1994

Table 2.28: Scale for estimating sorghum crop yield relative to water satisfaction index (WSI) for Kordofan Region historical data

Crop yield (%)	WSI (%)	Yield (kg/ha)	Crop yield (%)	WSI (%)	Yield (kg/ha)
>100	100	> 748		74	310
100	99	748		73	298
	98	730		72	285
	97	711		71	274
	96	692		70	263
90	95	673		69	251
	94	651		68	240
	93	631		67	229
	92	612		66	218
	91	592		65	207
	90	573		64	196
	89	553		63	184
	88	533		62	173
	87	514		61	161
	86	495	20	60	150
	85	476		59	143
	84	456		58	136
	83	437		57	129
	82	417		56	123
	81	398		55	117
50	80	379		54	110
	79	368		53	103
	78	357		52	96
	77	346		51	89
	76	334		50	75
	75	323	< 10	<50	< 75

Notes:

1. WSI = Water Satisfaction Index in % for crop monitoring.

2. The maximum crop yield obtained from the average of the best three years: 76/77 (721 kg/ha), 77/78 (683 kg/ha) and 78/79 (769 kg/ha). Average for the best three years is 748 kg/ha.

Table 2.29: Scale for estimating millet crop yield relative to water satisfaction index (WSI) for Kordofan Region historical data

Crop yield (%)	WSI (%)	Yield (kg/ha)	Crop yield (%)	WSI (%)	Yield (kg/ha)
>100	100	> 433		74	178
100	99	433		73	172
	98	422		72	165
	97	412		71	159
	96	401		70	152
90	95	390		69	145
	94	378		68	138
	93	367		67	132
	92	355		66	125
	91	343		65	118
	90	331		64	112
	89	320		63	105
	88	308		62	99
	87	296		61	92
	86	285	20	60	86
	85	273		59	81
	84	262		58	77
	83	251		57	73
	82	240		56	69
	81	228		55	65
50	80	217		54	61
	79	211		53	56
	78	204		52	52
	77	198		51	47
	76	191		50	43
	75	184	< 10	<50	<43

Notes:

1. WSI = Water Satisfaction Index in % for crop monitoring.

2. The maximum crop yield obtained from the average of the best three years: 70/71 (470 kg/ha), 78/79 (405 kg/ha) and 80/81 (427 kg/ha). Average for the best three years is 433 kg/ha.

Table 2.30: Predicted values of water satisfaction index (WSI) for millet relative to temperature and precipitation changes (for synthetic scenarios)

		Water satisfaction Index (%)				
		EL OBEID	**EN NAHUD**	**RASHAD**	**KADUGLI**	**BABANUSA**
Baseline		64	78	100	99	91
ΔP=-20%	ΔT=1.5˚C	49	60	74	60	57
	ΔT=2.5˚C	49	60	74	60	57
	ΔT=3.5˚C	48	59	73	59	56
	ΔT=4.5˚C	48	59	71	58	55
ΔP=-10%	ΔT=1.5˚C	52	64	83	67	63
	ΔT=2.5˚C	64	64	83	67	63
	ΔT=3.5˚C	51	63	81	66	61
	ΔT=4.5˚C	50	63	79	64	60
ΔP=0%	ΔT=1.5˚C	55	68	90	76	69
	ΔT=2.5˚C	54	67	89	74	68
	ΔT=3.5˚C	53	66	87	73	67
	ΔT=4.5˚C	43	56	84	70	59
ΔP=+10%	ΔT=1.5˚C	57	71	94	83	74
	ΔT=2.5˚C	57	71	94	83	74
	ΔT=3.5˚C	56	70	92	82	72
	ΔT=4.5˚C	55	69	91	80	71
ΔP=+20%	ΔT=1.5˚C	59	74	99	90	79
	ΔT=2.5˚C	59	74	99	90	79
	ΔT=3.5˚C	58	74	97	89	78
	ΔT=4.5˚C	57	73	96	87	76

Table 2.31: Predicted values of water satisfaction index (WSI) for gum arabic relative to temperature and precipitation changes (for synthetic scenarios)

		Water satisfaction Index (%)				
		EL OBEID	**EN NAHUD**	**RASHAD**	**KADUGLI**	**BABANUSA**
Baseline		11	14	56	59	26
ΔP=-20%	ΔT=1.5˚C	7	10	35	37	15
	ΔT=2.5˚C	7	10	35	37	15
	ΔT=3.5˚C	7	9	34	36	15
	ΔT=4.5˚C	7	9	34	36	15
ΔP=-10%	ΔT=1.5˚C	8	11	39	41	17
	ΔT=2.5˚C	8	11	39	41	17
	ΔT=3.5˚C	8	11	39	41	17
	ΔT=4.5˚C	8	11	38	40	17
ΔP=0%	ΔT=1.5˚C	9	12	44	46	19
	ΔT=2.5˚C	9	12	44	46	19
	ΔT=3.5˚C	9	12	43	45	19
	ΔT=4.5˚C	9	12	42	45	18
ΔP=+10%	ΔT=1.5˚C	10	13	48	50	21
	ΔT=2.5˚C	10	13	48	50	21
	ΔT=3.5˚C	10	13	47	50	21
	ΔT=4.5˚C	10	13	46	49	20
ΔP=+20%	ΔT=1.5˚C	11	15	52	55	23
	ΔT=2.5˚C	11	15	52	55	23
	ΔT=3.5˚C	11	14	51	54	23
	ΔT=4.5˚C	10	14	50	53	20

Table 2.32: Predicted values of water satisfaction index (WSI) for gum arabic relative to temperature and precipitation changes (for synthetic scenarios)

		Water satisfaction Index (%) Kordofan Region
Baseline		33
ΔP=-20%	ΔT=1.5˚C	23
	ΔT=2.5˚C	23
	ΔT=3.5˚C	23
	ΔT=4.5˚C	23
ΔP=-10%	ΔT=1.5˚C	21
	ΔT=2.5˚C	21
	ΔT=3.5˚C	20
	ΔT=4.5˚C	21
ΔP=0%	ΔT=1.5˚C	26
	ΔT=2.5˚C	26
	ΔT=3.5˚C	25
	ΔT=4.5˚C	25
ΔP=+10%	ΔT=1.5˚C	36
	ΔT=2.5˚C	31
	ΔT=3.5˚C	28
	ΔT=4.5˚C	28
ΔP=+20%	ΔT=1.5˚C	31
	ΔT=2.5˚C	31
	ΔT=3.5˚C	31
	ΔT=4.5˚C	28

Table 2.33: Gum arabic yield relative to temperature and precipitation changes (for synthetic scenarios)

		Yield (kg/ha) Kordofan Region
Baseline		16.1
ΔP=-20%	ΔT=1.5˚C	10.5
	ΔT=2.5˚C	10.5
	ΔT=3.5˚C	10.0
	ΔT=4.5˚C	10.0
ΔP=-10%	ΔT=1.5˚C	11.4
	ΔT=2.5˚C	11.4
	ΔT=3.5˚C	11.4
	ΔT=4.5˚C	11.4
ΔP=0%	ΔT=1.5˚C	12.9
	ΔT=2.5˚C	12.9
	ΔT=3.5˚C	12.4
	ΔT=4.5˚C	12.4
ΔP=+10%	ΔT=1.5˚C	13.5
	ΔT=2.5˚C	13.5
	ΔT=3.5˚C	13.5
	ΔT=4.5˚C	13.5
ΔP=+20%	ΔT=1.5˚C	15.0
	ΔT=2.5˚C	15.0
	ΔT=3.5˚C	15.0
	ΔT=4.5˚C	14.5

Table 2.34: Locations of the selected stations in Kordofan

Station	Latitude	Longitude	Altitude above MSL (meters)
El Obeid	13º 10' N	30º 14' E	570
En Nahud	12º 42' N	28º 26' E	565
Rashad	11º 52' N	31º 03' E	885
Kadugli	11º 00' N	29º 43' E	500
Babanusa	11 º20 N	27 º40 E	543

Table 2.35: Predicted sorghum yield relative to temperature and precipitation changes (for synthetic scenarios)

		Yield (kg/ha)				
		EL OBEID	**EN NAHUD**	**RASHAD**	**KADUGLI**	**BABANUSA**
Baseline		495	631	>748	>748	>748
ΔP=-20%	ΔT=1.5˚C	161	298	495	251	240
	ΔT=2.5˚C	161	298	495	251	240
	ΔT=3.5˚C	150	285	651	240	229
	ΔT=4.5˚C	143	274	437	229	218
ΔP=-10%	ΔT=1.5˚C	196	334	612	334	310
	ΔT=2.5˚C	196	334	612	334	310
	ΔT=3.5˚C	184	334	592	334	298
	ΔT=4.5˚C	173	495	573	310	274
ΔP=0%	ΔT=1.5˚C	229	379	711	495	398
	ΔT=2.5˚C	218	379	692	456	368
	ΔT=3.5˚C	207	368	673	437	357
	ΔT=4.5˚C	89	251	573	346	240
ΔP=+10%	ΔT=1.5˚C	251	437	748	631	495
	ΔT=2.5˚C	251	437	748	631	495
	ΔT=3.5˚C	240	437	748	612	476
	ΔT=4.5˚C	229	417	730	573	456
ΔP=+20%	ΔT=1.5˚C	274	514	>748	748	533
	ΔT=2.5˚C	274	514	>748	>748	533
	ΔT=3.5˚C	263	495	>748	>748	514
	ΔT=4.5˚C	251	495	>748	780	495

Table 2.36: Predicted millet yield relative to temperature and precipitation changes (for synthetic scenarios)

		Yield (kg/ha)				
		EL OBEID	**EN NAHUD**	**RASHAD**	**KADUGLI**	**BABANUSA**
Baseline		112	204	>433	433	343
ΔP=-20%	ΔT=1.5˚C	<43	86	178	86	73
	ΔT=2.5˚C	<43	86	178	86	73
	ΔT=3.5˚C	<43	81	172	81	69
	ΔT=4.5˚C	<43	81	159	77	65
ΔP=-10%	ΔT=1.5˚C	52	112	251	132	105
	ΔT=2.5˚C	52	112	251	132	105
	ΔT=3.5˚C	47	105	228	125	92
	ΔT=4.5˚C	43	105	211	112	86
ΔP=0%	ΔT=1.5˚C	65	138	331	191	145
	ΔT=2.5˚C	61	132	320	172	138
	ΔT=3.5˚C	56	125	296	172	132
	ΔT=4.5˚C	<43	69	262	152	81
ΔP=+10%	ΔT=1.5˚C	73	159	378	251	178
	ΔT=2.5˚C	73	159	378	251	78
	ΔT=3.5˚C	69	152	355	240	165
	ΔT=4.5˚C	65	145	343	217	159
ΔP=+20%	ΔT=1.5˚C	81	178	433	331	211
	ΔT=2.5˚C	81	178	433	331	211
	ΔT=3.5˚C	77	178	412	320	204
	ΔT=4.5˚C	73	315	401	296	191

Table 2.37: Predicted values of moisture index (%) from for baseline and GCMs in baseline and under climate change

		HADCM2		**BMRC**		**GFDL**	
Station	**Baseline**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
El Obeid	-57	-63	-66	-61	-59	-64	-64
En Nahud	-45	-55	-57	-51	-48	-56	-60
Rashad	-20	-25	-26	-25	-27	-23	-41
Kadugli	-13	-32	-35	-33	-36	-31	-44
Babanusa	-28	-45	-49	-47	-50	-44	-46

1 Table applies to both sorghum and millet crops in traditional rainfed farming in Kordofan

2 GCM outputs correspond to the IS92A scenario.

Table 2.38: Predicted values of water satisfaction index (WSI) for sorghum and millet in baseline and under climate change

		HADCM2		BMRC		GFDL	
	Baseline	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
				WSI (%) for Sorghum			
El Obeid	86	61	57	61	63	59	58
En Nahud	93	72	68	74	77	70	69
Rashad	100	100	100	100	99	100	100
Kadugli	100	88	85	87	84	89	89
Babanusa	100	83	78	81	78	83	83
				WSI (%) for Millet			
El Obeid	64	49	46	51	53	48	47
En Nahud	78	60	56	62	65	58	57
Rashad	99	92	90	92	90	94	91
Kadugli	99	77	73	75	72	77	77
Babanusa	91	72	67	70	66	72	71

1 Baseline corresponds to the 1961-1990 periods and also holds for 2030 and 2060.
Applies to traditional rainfed farming in Kordofan
2 GCM outputs correspond to the IS92A scenario

Table 2.39: Predicted values of crop yield for sorghum and millet in baseline and under climate change

		HADCM2		BMRC		GFDL	
	Baseline	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
				Crop yield (kg/ha) for Sorghum			
El Obeid	495	161	129	161	184	143	136
En Nahud	631	150	240	310	346	263	251
Rashad	>748	>748	>748	>748	748	>748	>748
Kadugli	>748	533	476	514	456	553	553
Babanusa	>748	285	357	398	357	437	473
				Crop yield (kg/ha) for Millet			
El Obeid	112	<43	<43	47	56	<43	<43
En Nahud	402	86	123	99	118	77	145
Rashad	433	355	331	355	331	378	343
Kadugli	433	198	172	184	165	198	198
Babanusa	343	165	132	152	125	165	159

1 Baseline corresponds to the 1961-1990 periods and also holds for 2030 and 2060.
Applies to traditional rainfed farming in Kordofan

2 GCM outputs correspond to the IS92A scenario

Table 2.40: Predicted values of moisture index (Im) and water satisfaction index (WSI) for gum arabic in baseline and under climate change change

		HADCM2		BMRC		GFDL	
	Baseline	2030	2060	2030	2060	2030	2060
				Moisture Index (%)			
El Obeid	-72	-75	-77	-74	-73	-76	-75
En Nahud	-62	-68	-70	-66	-64	-69	-70
Rashad	-32	-35	-36	-34	-36	-33	-49
Kadugli	-19	-42	-44	-42	-44	-41	-53
Babanusa	-46	-57	-60	-58	-60	-57	-58
				Water Satisfaction Index (%)			
El Obeid	11	13	12	15	16	14	14
En Nahud	14	12	12	13	14	12	13
Rashad	56	52	53	52	56	53	56
Kadugli	59	43	44	44	47	44	45
Babanusa	26	24	24	26	29	25	26

Table 2.41: Predicted values of water satisfaction index and crop yield for gum arabic in Kordofan in baseline and under climate change

		HADCM2		BMRC		GFDL	
	Baseline	2030	2060	2030	2060	2030	2060
Water Satisfaction Index (%)	33	29	29	30	32	30	31
Crop yield (kg/ha)	16.1	14.0	14.0	14.5	15.5	14.5	15.0

1 GCM outputs correspond to the IS92A scenario.

Table 2.42: Summary table for sorghum

		1961-1990			2030			2060		
Station	T and P	Im (%)	WSI (%)	Yield (kg/ha)	Im (%)	WSI (%)	Yield (kg/ha)	Im (%)	WSI (%)	Yield (kg/ha)
El Obeid	See Tables 3.5, 3.6 &3.7 as input parameters for models HADCM2, BMRC AND GFDL	-57	86	495	-63	60	155	-63	59	150
En Nahud		-45	93	631	-54	72	241	-55	71	279
Rashad		-20	100	>748	-24	100	>748	-31	100	748
Kadugli		-13	100	>748	-32	88	533	-38	86	495
Babanusa		-28	100	>748	-45	82	373	-48	80	396

T = temperature
P = precipitation

Table 2.43: Summary table for millet

Station	T and P	1961-1990			2030			2060		
		Im (%)	WSI (%)	Yield (kg/ha)	Im (%)	WSI (%)	Yield (kg/ha)	Im (%)	WSI (%)	Yield (kg/ha)
El Obeid	See Tables 3.5, 3.6 &3.7 as input parameters for models HADCM2, BMRC AND GFDL	-57	64	112	-63	53	<43	-63	49	<43
En Nahud		-45	78	402	-54	60	87	-55	59	129
Rashad		-20	99	433	-24	93	362	-31	90	335
Kadugli		-13	99	433	-32	80	193	-38	74	178
Babanusa		-28	91	343	-45	71	161	-48	68	139

T = temperature
P = precipitation

Table 2.44: Predicted values in gum arabic yield derived from WSI input in milestone years in Kordofan Region in baseline and under climate change

		HADCM2		BMRC		GFDL	
Station	Baseline	2030	2060	2030	2060	2030	2060
El Obeid	5.6	7	6.2	7.6	8.1	7.1	7.1
En Nahud	6.6	6.2	6.6	6.6	7.1	6.2	6.6
Rashad	>16.1	>16.1	>16.1	>16.1	>16.1	>16.1	>16.1
Kadugli	>16.1	>16.1	>16.1	>16.1	>16.1	>16.1	>16.1
Babanusa	12.9	11.9	11.9	12.9	14	12.4	12.9

GCM outputs correspond to the IS92A scenario

3. Human Health and Malaria

3.1 Malaria Modeling Methods

Equations from the MIASMA model (Modeling framework for the health Impact Assessment of Man Induced Atmospheric Changes) were replicated in spreadsheet format and used to calculate changes in epidemic potential of malaria. These calculations were made for the four states of Kordofan Region, for the years 2030 and 2060. The results were compared to calculations of a baseline epidemic potential (1951-1980).

MIASMA, developed by Pim Martens of Maastricht University, in The Netherlands, is a tool which integrates several models, dealing with health impacts of global atmospheric changes. As in each of the sectoral impact assessments, baseline scenarios are measured against climate change scenarios (generated with the Magicc/Scengen software and a selection of GCM models) in milestone years 2030 and 2060, in order to gauge the regional impacts of changes in climate (see scenario methodology section for more detail).

Table 3.1: Default Values

Parameter	Description	Default value	Local value (DV)
D_m	Degree days for parasite development	T-dependent; P.Vivax: 105ºC-day P.Falciparum: 111ºC-day	NA
$T_{min.m}$	Minimum temp. parasite development	14.5ºC P.Vivax 16ºC P.Falciparum	NA
HPI	Human blood index	T-dependent; 0.4	NA
FI	Feeding interval	T-dependent	NA
D_{bd}	Degree days-blood digestion	36.5^{o}C	NA
T_{minbd}	Min. temp blood for blood digestion	9.9^{o}C-day	NA
P	Survival probability	T-dependent Max: 0.9/day at 20ºC	NA
b	Human susceptibility	1	NA
c	Mosquito susceptibility	1	NA

1. NA = not applicable

The equations and assumptions from the MIASMA model are described in detail below. Each of the equations and most of the details presented below regarding vector longevity and transmissivity are based on Martens (1998). In all cases where default values were provided, these were used, primarily due to a lack of local research and shortage of the detailed data required to justify significant adjustments to the model. Table 3.1 shows the default values used in the assessment.

3.1.1 Malaria Vector Survival Potential

According to Martens, longevity of the mosquito vector depends mainly on the vector species, humidity and the availability of host and temperature. In order for the transmission of the parasite to a human, the female mosquito must live long enough for the parasite to complete its development. The optimum temperature range for this to occur is between 20° C and 25° C. Mosquitoes will die in temperature that exceed this range, and a threshold temperature exists above which rapid mosquito death is inevitable.

On the other hand, the minimum temperature below which the mosquito can not become active. Based on the work of Boyd (1949), Horsfall (1955), and Clements and Patterson (1981), as reported in Martens, the daily survival probabilities are 0.82, 0.9, and 0.4 at temperatures of 9°, 20°, and 40° Celsius, respectively. Survival potential is expressed as follows:

$$p = e^{-1/(-4.4 + 1.3T - 0.03T^2)}$$

where: p = *survival potential (fraction of population per day)*

T = *temperature (^oC)*

-4.4, 1.3, -0.03 are empirically-based constants

3.1.2 Frequency of Blood Meals by Mosquito

The frequency at which a mosquito feeds depends mainly on how rapidly a blood meal is digested (Petirova et al., 1962; Sevice,1980). As temperature increases, this frequency increases. The frequency and can be estimated by the following formula (Martens, 1998):

$$a = HBI / (D_{bd} / (T - T_{min,bd}))$$

where: a = *frequency with which human blood meals are taken (/day)*

HBI = Human Blood Index (estimated proportion of blood meals taken by a mosquito population which are obtained from humans).

The Human Blood Index provides an indication as to whether a mosquito species is anthropophilic in its feeding behavior (a high HBI indicates a preference for biting man) or azoophilic (a low HBI indicates a population which feeds mainly on animals).

The HBI is set to 0.4 , a value frequently found in malaria endemic regions for a wide range of anophiline species (Garett-Jones *et al*. 1980). The frequency of feeding depends mainly on the rapidity with which a blood meal is digested (Detinova et al 1962) which increase as temperature rises and can be calculated by the sum of temperatures (Detinova et al 1962).

$$FI = D_{bd}/T - T_{minbd}$$

Where:

Dbd = number of degree days required for the digestion of a portion of ingested blood (36.5C days at a humidity of 70-80 percent)

FI =Frequency Interval

Tminbd = Minimum temperature required for digestion of blood meal (9.9˚ C)

A female mosquito has to live long enough for the parasite to complete its development if transmission is to occur. Longevity of the mosquito vector depends mainly on the vector species, humidity, the availability of hosts and temperature. Default value = 0.9/day at 20˚ C.

3.1.3 Incubation Period of the Parasite inside the Vector

In order for the infected mosquito to transmit the parasite to a human or animal, the incubation period of the parasite in the mosquito (Extrinsic Incubation Period (EIP)) must have elapsed. The parasites are able to develop within the mosquito within a certain temperature range. For *P. vivax,* the minimum temperature for parasite development lies between 14.5˚ and 15˚ C. For *P. Falciparum,* the minimum temperature for parasite development lies between 16˚ and 19˚ C. The proportion of parasites that survive temperature outside of these ranges decreases rapidly at temperatures over 32˚ and 34˚ C.

The relation between ambient temperature and incubation period is calculated as:

$$n = D_m / (T - T_{min,m})$$

where: *n = incubation period of the parasite inside the vector (days) 105˚C days and 111˚ C day for Vivax and falciparum respectively)*

D_m = number of degree-days required for the development of the parasite

T = temperature

$T_{min,m}$ = minimum temperature required for parasite development

3.1.4 Malaria Transmission Potential

The critical density (m_{c1}) in mosquitoes per human for malaria transmission can be expressed as :

$$m_{c1} = c_1 \left[(-\ln(p) / bca^2p^n \right]$$

where: *m_{c1} = epidemic potential*

p = survival potential (/day)

b = efficiency with which an infective mosquito infects a human

c = efficiency with which an infective human infects a mosquito

a = frequency with which human blood meals are taken (/day)

3.1.5 Limitations and uncertainties

A number of uncertainties are encountered in the use of this MIASMA-based model - and all models of its type. A number of classifications can be made. Here, the various types and sources of uncertainty are aggregated into two categories (Rotmans *et al.*,1994): (a) *scientific uncertainties* arise from the degree of unpredictability of global atmospheric change processes and their impact upon human health; (b) *social and economic uncertainties* arise from the inherent unpredictability of future geopolitical, socioeconomic, demographic, and technological evolution. Both of these apply to the work undertaken for this component of the assessment. As MIASMA is designed as a global model, and may have limitations at the regional level, care must be taken in making and interpreting conclusions based on the model outcomes. The regional conclusions derived through this work are stated with a degree of caution given the current limitations in modeling regional malaria transmission.

3.2 Results

The following tables summarize the changes in transmission potential risk. Results for projected average monthly transmission potential are presented for each GCM and each milestone year, and are compared with average monthly baseline transmission. Figure 3.3 and 3.4 illustrate the change in transmission potential in 2030 and 2060.

Table 3.2: Projected average transmission potential of P. Vivax at using HADCM2 outputs

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
El Obeid	Baseline climate	0.24	0.45	0.82	1.00	0.98	1.00	0.90	0.82	0.89	0.97	0.67	0.27
	Climate change scenario: 2030	0.35	0.58	0.92	0.98	0.90	0.98	0.99	0.95	0.98	1.00	0.81	0.42
	Climate change scenario: 2060	0.45	0.69	0.98	0.92	0.70	0.85	1.02	0.99	1.01	0.98	0.90	0.50
	Ratio of climate change baseline: 2030	1.44	1.30	1.13	0.98	0.92	0.98	1.10	1.16	1.10	1.03	1.20	1.54
	Ratio of climate change baseline: 2060	1.85	1.54	1.20	0.92	0.71	0.85	1.13	1.20	1.13	1.01	1.34	1.81
En Nahud	Baseline climate	0.27	0.49	0.84	1.01	0.98	0.99	0.90	0.84	0.91	0.95	0.67	0.34
	Climate change scenario: 2030	0.37	0.63	0.95	0.98	0.91	0.98	0.99	0.97	1.00	0.99	0.81	0.46
	Climate change scenario: 2060	0.48	0.74	0.99	0.92	0.77	0.90	1.01	0.99	0.98	0.98	0.90	0.56
	Ratio of climate change baseline: 2030	1.41	1.31	1.12	0.97	0.93	0.99	1.09	1.15	1.10	1.04	1.20	1.36
	Ratio of climate change baseline: 2060	1.80	1.52	1.18	0.91	0.78	0.91	1.12	1.18	1.08	1.03	1.34	1.66
Rashad	Baseline climate	0.53	0.69	0.90	1.00	0.96	0.81	0.60	0.58	0.63	0.77	0.77	0.60
	Climate change scenario: 2030	0.59	0.75	0.95	1.00	1.00	0.87	0.69	0.67	0.71	0.84	0.83	0.67
	Climate change scenario: 2060	0.66	0.80	0.97	0.98	0.99	0.91	0.75	0.74	0.77	0.89	0.88	0.72
	Ratio of climate change baseline: 2030	1.11	1.10	1.05	1.00	1.04	1.08	1.15	1.15	1.12	1.09	1.08	1.13
	Ratio of climate change baseline: 2060	1.23	1.16	1.07	0.98	1.03	1.13	1.26	1.27	1.22	1.16	1.15	1.20
Kadugli	Baseline climate	0.67	0.84	0.99	0.98	0.98	0.92	0.77	0.71	0.75	0.84	0.82	0.71
	Climate change scenario: 2030	0.76	0.91	1.02	0.93	0.93	0.97	0.87	0.82	0.85	0.92	0.91	0.81
	Climate change scenario: 2060	0.83	0.96	0.98	0.90	0.90	0.99	0.93	0.90	0.91	0.97	0.96	0.87
	Ratio of climate change baseline: 2030	1.13	1.08	1.03	0.95	0.95	1.06	1.13	1.16	1.13	1.09	1.11	1.13
	Ratio of climate change baseline: 2060	1.23	1.14	0.99	0.92	0.92	1.07	1.21	1.27	1.22	1.15	1.16	1.22
Babanusa	Baseline climate	0.48	0.79	1.00	0.98	0.94	0.86	0.85	0.82	0.88	0.96	0.89	0.69
	Climate change scenario: 2030	0.59	0.88	1.02	0.90	0.85	0.95	0.95	0.93	0.97	0.99	0.97	0.80
	Climate change scenario: 2060	0.69	0.93	0.98	0.78	0.73	0.99	1.00	0.98	1.01	0.98	1.00	0.87
	Ratio of climate change baseline: 2030	1.24	1.12	1.01	0.92	0.90	1.10	1.12	1.12	1.11	1.04	1.09	1.16
	Ratio of climate change baseline: 2060	1.44	1.18	0.98	0.79	0.78	1.15	1.17	1.19	1.16	1.02	1.13	1.26

Table 3.3: Projected average transmission potential of P. Falciparum at using HADCM2 outputs

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
El Obeid	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
En Nahud	Baseline climate	0.19	0.42	0.82	1.01	0.98	0.99	0.88	0.82	0.89	0.94	0.62	0.27
	Climate change scenario: 2030	0.30	0.59	0.93	0.98	0.91	0.98	0.98	0.96	1.00	0.99	0.77	0.39
	Climate change scenario: 2060	0.41	0.70	0.99	0.92	0.76	0.90	1.02	0.99	0.98	0.98	0.88	0.50
	Ratio of climate change baseline: 2030	1.56	1.40	1.14	0.97	0.93	0.99	1.11	1.18	1.12	1.05	1.24	1.47
	Ratio of climate change baseline: 2060	2.13	1.66	1.22	0.91	0.77	0.91	1.15	1.22	1.10	1.04	1.40	1.87
Rashad	Baseline climate	0.48	0.64	0.88	1.00	0.95	0.77	0.54	0.52	0.58	0.74	0.74	0.54
	Climate change scenario: 2030	0.54	0.72	0.94	1.00	1.00	0.85	0.64	0.62	0.66	0.81	0.81	0.63
	Climate change scenario: 2060	0.61	0.77	0.96	0.98	0.99	0.89	0.72	0.70	0.73	0.87	0.86	0.67
	Ratio of climate change baseline: 2030	1.12	1.12	1.06	1.00	1.05	1.09	1.19	1.19	1.14	1.10	1.10	1.16
	Ratio of climate change baseline: 2060	1.28	1.19	1.09	0.98	1.04	1.15	1.32	1.33	1.27	1.19	1.17	1.25
Kadugli	Baseline climate	0.62	0.82	0.99	0.98	0.98	0.91	0.74	0.66	0.71	0.82	0.80	0.67
	Climate change scenario: 2030	0.72	0.89	1.02	0.93	0.93	0.97	0.85	0.79	0.83	0.91	0.89	0.78
	Climate change scenario: 2060	0.80	0.95	0.98	0.90	0.90	0.99	0.92	0.88	0.90	0.96	0.95	0.85
	Ratio of climate change baseline: 2030	1.16	1.09	1.04	0.95	0.95	1.07	1.15	1.19	1.16	1.11	1.12	1.16
	Ratio of climate change baseline: 2060	1.28	1.16	1.00	0.92	0.92	1.09	1.25	1.32	1.26	1.17	1.19	1.26
Babanusa	Baseline climate	0.41	0.76	1.00	0.98	0.95	0.83	0.83	0.80	0.85	0.95	0.86	0.64
	Climate change scenario: 2030	0.54	0.86	1.02	0.90	0.84	0.93	0.94	0.91	0.96	0.99	0.96	0.77
	Climate change scenario: 2060	0.64	0.92	0.98	0.77	0.73	0.98	0.99	0.97	1.01	0.98	1.00	0.85
	Ratio of climate change baseline: 2030	1.30	1.14	1.02	0.92	0.89	1.12	1.14	1.15	1.13	1.05	1.11	1.19
	Ratio of climate change baseline: 2060	1.56	1.22	0.98	0.78	0.77	1.18	1.20	1.22	1.19	1.03	1.16	1.32

Table 3.4: Projected average transmission potential of P. Vivax at using BMRC outputs

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
El Obeid	Baseline climate	0.24	0.45	0.82	1.00	0.98	1.00	0.90	0.82	0.89	0.97	0.67	0.27
	Climate change scenario: 2030	0.27	0.53	0.87	0.99	0.94	0.98	0.94	0.84	0.90	0.97	0.72	0.37
	Climate change scenario: 2060	0.33	0.59	0.90	1.01	0.92	0.98	0.97	0.86	0.91	0.98	0.77	0.44
	Ratio of climate change baseline: 2030	1.11	1.19	1.06	0.99	0.96	0.98	1.05	1.02	1.01	1.00	1.07	1.33
	Ratio of climate change baseline: 2060	1.34	1.32	1.11	1.00	0.94	0.98	1.08	1.04	1.02	1.01	1.16	1.60
En Nahud	Baseline climate	0.27	0.49	0.84	1.01	0.98	0.99	0.90	0.84	0.91	0.95	0.67	0.34
	Climate change scenario: 2030	0.37	0.63	0.95	0.98	0.91	0.98	0.99	0.97	1.00	0.99	0.81	0.46
	Climate change scenario: 2060	0.48	0.74	0.99	0.92	0.77	0.90	1.01	0.99	0.98	0.98	0.90	0.56
	Ratio of climate change baseline: 2030	1.41	1.31	1.12	0.97	0.93	0.99	1.09	1.15	1.10	1.04	1.20	1.36
	Ratio of climate change baseline: 2060	1.80	1.52	1.18	0.91	0.78	0.91	1.12	1.18	1.08	1.03	1.34	1.66
Rashad	Baseline climate	0.53	0.69	0.90	1.00	0.96	0.81	0.60	0.58	0.63	0.77	0.77	0.60
	Climate change scenario: 2030	0.59	0.75	0.95	1.00	1.00	0.87	0.69	0.67	0.71	0.84	0.83	0.67
	Climate change scenario: 2060	0.6	0.80	0.97	0.98	0.99	0.91	0.75	0.74	0.77	0.89	0.88	0.72
	Ratio of climate change baseline: 2030	1.11	1.10	1.05	1.00	1.04	1.08	1.15	1.15	1.12	1.09	1.08	1.13
	Ratio of climate change baseline: 2060	1.23	1.16	1.07	0.98	1.03	1.13	1.26	1.27	1.22	1.16	1.15	1.20
Kadugli	Baseline climate	0.67	0.84	0.99	0.98	0.98	0.92	0.77	0.71	0.75	0.84	0.82	0.71
	Climate change scenario: 2030	0.76	0.91	1.02	0.93	0.93	0.97	0.87	0.82	0.85	0.92	0.91	0.81
	Climate change scenario: 2060	0.83	0.96	0.98	0.90	0.90	0.99	0.93	0.90	0.91	0.97	0.96	0.87
	Ratio of climate change baseline: 2030	1.13	1.08	1.03	0.95	0.95	1.06	1.13	1.16	1.13	1.09	1.11	1.13
	Ratio of climate change baseline: 2060	1.23	1.14	0.99	0.92	0.92	1.07	1.21	1.27	1.22	1.15	1.16	1.22
Babanusa	Baseline climate	0.48	0.79	1.00	0.98	0.94	0.86	0.85	0.82	0.88	0.96	0.89	0.69
	Climate change scenario: 2030	0.59	0.88	1.02	0.90	0.85	0.95	0.95	0.93	0.97	0.99	0.97	0.80
	Climate change scenario: 2060	0.69	0.93	0.98	0.78	0.73	0.99	1.00	0.98	1.01	0.98	1.00	0.87
	Ratio of climate change baseline: 2030	1.24	1.12	1.01	0.92	0.90	1.10	1.12	1.12	1.11	1.04	1.09	1.16
	Ratio of climate change baseline: 2060	1.44	1.18	0.98	0.79	0.78	1.15	1.17	1.19	1.16	1.02	1.13	1.26

Table 3.5: Projected average transmission potential of P. Falciparum at using BMRC outputs

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
El Obeid	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	0.20	0.47	0.84	0.99	0.94	0.98	0.93	0.82	0.88	0.96	0.67	0.29
	Climate change scenario: 2060	0.26	0.53	0.88	1.01	0.92	0.99	0.96	0.84	0.89	0.97	0.74	0.37
	Ratio of climate change baseline: 2030	1.11	1.24	1.07	0.99	0.96	0.98	1.05	1.03	1.01	1.00	1.08	1.48
	Ratio of climate change baseline: 2060	1.47	1.40	1.13	1.01	0.93	0.99	1.09	1.05	1.02	1.01	1.19	1.88
En Nahud	Baseline climate	0.19	0.42	0.82	1.01	0.98	0.99	0.88	0.82	0.89	0.94	0.62	0.27
	Climate change scenario: 2030	0.30	0.59	0.93	0.98	0.91	0.98	0.98	0.96	1.00	0.99	0.77	0.39
	Climate change scenario: 2060	0.41	0.70	0.99	0.92	0.76	0.90	1.02	0.99	0.98	0.98	0.88	0.50
	Ratio of climate change baseline: 2030	1.56	1.40	1.14	0.97	0.93	0.99	1.11	1.18	1.12	1.05	1.24	1.47
	Ratio of climate change baseline: 2060	2.13	1.66	1.22	0.91	0.77	0.91	1.15	1.22	1.10	1.04	1.40	1.87
Rashad	Baseline climate	0.48	0.64	0.88	1.00	0.95	0.77	0.54	0.52	0.58	0.74	0.74	0.54
	Climate change scenario: 2030	0.54	0.72	0.94	1.00	1.00	0.85	0.64	0.62	0.66	0.81	0.81	0.63
	Climate change scenario: 2060	0.61	0.77	0.96	0.98	0.99	0.89	0.72	0.70	0.73	0.87	0.86	0.67
	Ratio of climate change baseline: 2030	1.12	1.12	1.06	1.00	1.05	1.09	1.19	1.19	1.14	1.10	1.10	1.16
	Ratio of climate change baseline: 2060	1.28	1.19	1.09	0.98	1.04	1.15	1.32	1.33	1.27	1.19	1.17	1.25
Kadugli	Baseline climate	0.62	0.82	0.99	0.98	0.98	0.91	0.74	0.66	0.71	0.82	0.80	0.67
	Climate change scenario: 2030	0.72	0.89	1.02	0.93	0.93	0.97	0.85	0.79	0.83	0.91	0.89	0.78
	Climate change scenario: 2060	0.80	0.95	0.98	0.90	0.90	0.99	0.92	0.88	0.90	0.96	0.95	0.85
	Ratio of climate change baseline: 2030	1.16	1.09	1.04	0.95	0.95	1.07	1.15	1.19	1.16	1.11	1.12	1.16
	Ratio of climate change baseline: 2060	1.28	1.16	1.00	0.92	0.92	1.09	1.25	1.32	1.26	1.17	1.19	1.26
Babanusa	Baseline climate	0.41	0.76	1.00	0.98	0.95	0.83	0.83	0.80	0.85	0.95	0.86	0.64
	Climate change scenario: 2030	0.54	0.86	1.02	0.90	0.84	0.93	0.94	0.91	0.96	0.99	0.96	0.77
	Climate change scenario: 2060	0.64	0.92	0.98	0.77	0.73	0.98	0.99	0.97	1.01	0.98	1.00	0.85
	Ratio of climate change baseline: 2030	1.30	1.14	1.02	0.92	0.89	1.12	1.14	1.15	1.13	1.05	1.11	1.19
	Ratio of climate change baseline: 2060	1.56	1.22	0.98	0.78	0.77	1.18	1.20	1.22	1.19	1.03	1.16	1.32

Table 3.6: Projected average transmission potential of P. Vivax using GFDL outputs

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
El Obeid	Baseline climate	0.24	0.45	0.82	1.00	0.98	1.00	0.90	0.82	0.89	0.97	0.67	0.27
	Climate change scenario: 2030	0.33	0.54	0.87	1.01	0.93	0.98	0.96	0.88	0.95	0.99	0.71	0.35
	Climate change scenario: 2060	0.42	0.65	0.93	0.98	0.91	0.93	0.99	0.92	0.98	0.98	0.75	0.37
	Ratio of climate change baseline: 2030	1.38	1.22	1.07	1.00	0.95	0.98	1.07	1.07	1.07	1.02	1.07	1.29
	Ratio of climate change baseline: 2060	1.75	1.45	1.14	0.98	0.92	0.93	1.10	1.12	1.10	1.02	1.11	1.35
En Nahud	Baseline climate	0.27	0.49	0.84	1.01	0.98	0.99	0.90	0.84	0.91	0.95	0.67	0.34
	Climate change scenario: 2030	0.37	0.63	0.95	0.98	0.91	0.98	0.99	0.97	1.00	0.99	0.81	0.46
	Climate change scenario: 2060	0.48	0.74	0.99	0.92	0.77	0.90	1.01	0.99	0.98	0.98	0.90	0.56
	Ratio of climate change baseline: 2030	1.41	1.31	1.12	0.97	0.93	0.99	1.09	1.15	1.10	1.04	1.20	1.36
	Ratio of climate change baseline: 2060	1.80	1.52	1.18	0.91	0.78	0.91	1.12	1.18	1.08	1.03	1.34	1.66
Rashad	Baseline climate	0.53	0.69	0.90	1.00	0.96	0.81	0.60	0.58	0.63	0.77	0.77	0.60
	Climate change scenario: 2030	0.59	0.75	0.95	1.00	1.00	0.87	0.69	0.67	0.71	0.84	0.83	0.67
	Climate change scenario: 2060	0.66	0.80	0.97	0.98	0.99	0.91	0.75	0.74	0.77	0.89	0.88	0.72
	Ratio of climate change baseline: 2030	1.11	1.10	1.05	1.00	1.04	1.08	1.15	1.15	1.12	1.09	1.08	1.13
	Ratio of climate change baseline: 2060	1.23	1.16	1.07	0.98	1.03	1.13	1.26	1.27	1.22	1.16	1.15	1.20
Kadugli	Baseline climate	0.67	0.84	0.99	0.98	0.98	0.92	0.77	0.71	0.75	0.84	0.82	0.71
	Climate change scenario: 2030	0.76	0.91	1.02	0.93	0.93	0.97	0.87	0.82	0.85	0.92	0.91	0.81
	Climate change scenario: 2060	0.83	0.96	0.98	0.90	0.90	0.99	0.93	0.90	0.91	0.97	0.96	0.87
	Ratio of climate change baseline: 2030	1.13	1.08	1.03	0.95	0.95	1.06	1.13	1.16	1.13	1.09	1.11	1.13
	Ratio of climate change baseline: 2060	1.23	1.14	0.99	0.92	0.92	1.07	1.21	1.27	1.22	1.15	1.16	1.22
Babanusa	Baseline climate	0.48	0.79	1.00	0.98	0.94	0.86	0.85	0.82	0.88	0.96	0.89	0.69
	Climate change scenario: 2030	0.59	0.88	1.02	0.90	0.85	0.95	0.95	0.93	0.97	0.99	0.97	0.80
	Climate change scenario: 2060	0.69	0.93	0.98	0.78	0.73	0.99	1.00	0.98	1.01	0.98	1.00	0.87
	Ratio of climate change baseline: 2030	1.24	1.12	1.01	0.92	0.90	1.10	1.12	1.12	1.11	1.04	1.09	1.16
	Ratio of climate change baseline: 2060	1.44	1.18	0.98	0.79	0.78	1.15	1.17	1.19	1.16	1.02	1.13	1.26

Table 3.7: Projected average transmission potential of P. Falciparum using GFDL outputs

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
El Obeid	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	0.27	0.49	0.85	1.01	0.93	0.98	0.95	0.86	0.94	0.99	0.67	0.28
	Climate change scenario: 2060	0.36	0.60	0.92	0.98	0.91	0.93	0.99	0.91	0.98	0.99	0.71	0.30
	Ratio of climate change baseline: 2030	1.52	1.27	1.09	1.01	0.95	0.98	1.08	1.08	1.08	1.03	1.08	1.43
	Ratio of climate change baseline: 2060	2.05	1.57	1.17	0.98	0.92	0.93	1.12	1.14	1.12	1.03	1.14	1.51
En Nahud	Baseline climate	0.19	0.42	0.82	1.01	0.98	0.99	0.88	0.82	0.89	0.94	0.62	0.27
	Climate change scenario: 2030	0.30	0.59	0.93	0.98	0.91	0.98	0.98	0.96	1.00	0.99	0.77	0.39
	Climate change scenario: 2060	0.41	0.70	0.99	0.92	0.76	0.90	1.02	0.99	0.98	0.98	0.88	0.50
	Ratio of climate change baseline: 2030	1.56	1.40	1.14	0.97	0.93	0.99	1.11	1.18	1.12	1.05	1.24	1.47
	Ratio of climate change baseline: 2060	2.13	1.66	1.22	0.91	0.77	0.91	1.15	1.22	1.10	1.04	1.40	1.87
Rashad	Baseline climate	0.48	0.64	0.88	1.00	0.95	0.77	0.54	0.52	0.58	0.74	0.74	0.54
	Climate change scenario: 2030	0.54	0.72	0.94	1.00	1.00	0.85	0.64	0.62	0.66	0.81	0.81	0.63
	Climate change scenario: 2060	0.61	0.77	0.96	0.98	0.99	0.89	0.72	0.70	0.73	0.87	0.86	0.67
	Ratio of climate change baseline: 2030	1.12	1.12	1.06	1.00	1.05	1.09	1.19	1.19	1.14	1.10	1.10	1.16
	Ratio of climate change baseline: 2060	1.28	1.19	1.09	0.98	1.04	1.15	1.32	1.33	1.27	1.19	1.17	1.25
Kadugli	Baseline climate	0.62	0.82	0.99	0.98	0.98	0.91	0.74	0.66	0.71	0.82	0.80	0.67
	Climate change scenario: 2030	0.72	0.89	1.02	0.93	0.93	0.97	0.85	0.79	0.83	0.91	0.89	0.78
	Climate change scenario: 2060	0.80	0.95	0.98	0.90	0.90	0.99	0.92	0.88	0.90	0.96	0.95	0.85
	Ratio of climate change baseline: 2030	1.16	1.09	1.04	0.95	0.95	1.07	1.15	1.19	1.16	1.11	1.12	1.16
	Ratio of climate change baseline: 2060	1.28	1.16	1.00	0.92	0.92	1.09	1.25	1.32	1.26	1.17	1.19	1.26
Babanusa	Baseline climate	0.41	0.76	1.00	0.98	0.95	0.83	0.83	0.80	0.85	0.95	0.86	0.64
	Climate change scenario: 2030	0.54	0.86	1.02	0.90	0.84	0.93	0.94	0.91	0.96	0.99	0.96	0.77
	Climate change scenario: 2060	0.64	0.92	0.98	0.77	0.73	0.98	0.99	0.97	1.01	0.98	1.00	0.85
	Ratio of climate change baseline: 2030	1.30	1.14	1.02	0.92	0.89	1.12	1.14	1.15	1.13	1.05	1.11	1.19
	Ratio of climate change baseline: 2060	1.56	1.22	0.98	0.78	0.77	1.18	1.20	1.22	1.19	1.03	1.16	1.32

Figure 3.1: Projected average increase in the transmission potential of P. Falciparum using combined GCM outputs (2030)

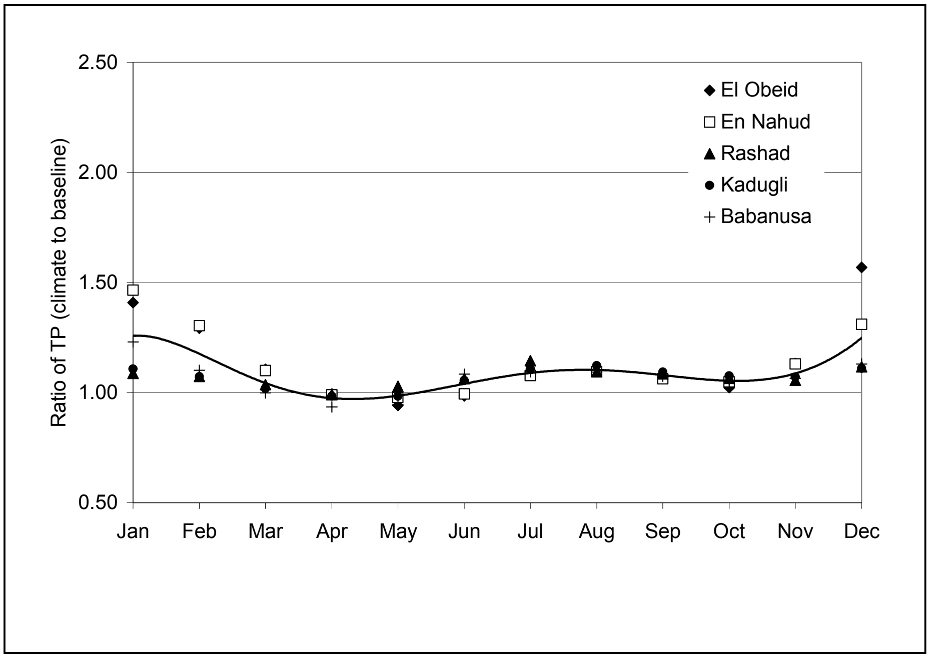
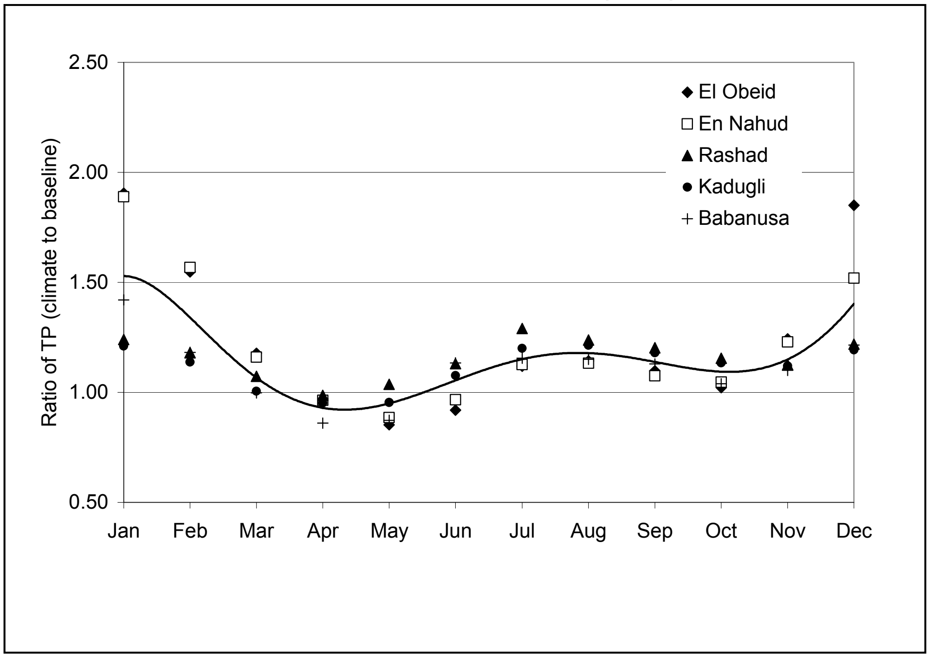


Figure 3.2: Projected average increase in the transmission potential of P. Falciparum using combined GCM outputs (2060)



4. Water Resources

Sudan is an arid country with levels of per capita water consumption well below the threshold of water scarcity. Rainfall in many parts of the country is extremely sparse and unreliable. The nation's water harvesting and storage capacities are presently minimal. Although 60% of the Nile basin is within Sudan's borders, the country's share of Nile waters is a mere 22%, according to the 1959 Agreement with Egypt. Seasonal streams flow for days, or mere hours, during the rainy season. Their flow comes in flushes which vary considerably in magnitude and duration. In regions such as Kordofan no permanent, year-round surface water exists.

The total annual flow of seasonal streams ranges between 3 and 7 billion of cubic meters (bcm).[5] The amount of groundwater storage is not yet quantified to a reasonable accuracy. However, the annual recharge is estimated to be around 4 bcm. Thus the flow of the seasonal streams and the recharge of groundwater amount to less than 10 bcm in most years. When this is added to the Sudan share in the Nile Waters, 20.5 bcm, the sum of internal and external water resources available to Sudan can be estimated at roughly 30 bcm. As the current population of Sudan is about 30 million, the per capita available water is around 1,000 cubic meters, placing Sudan well below the limit of water scarcity and into the range of water stress.

Despite this, Sudan has been utilizing just over half of its available water since the 1970s mainly because of the limited storage facilities.

Abstraction of groundwater is costly as most of the aquifers are located at depths from 40 to 400 meters. Nevertheless, it is the main source of water in many dry areas away from the Nile. The current total annual water abstraction is about 16 bcm. Around 94% of that abstraction goes to agriculture. A mere 5% goes to human (household) and animal watering needs, while just 1% goes to industry. It is anticipated that these percentages will change considerably in 25 years, with the shares anticipated to shift to 69% for agriculture, 18% for the industrial and hydropower requirements and 13% for household and animal watering needs.

In this study we tried to assess the potential impacts of climate change on Sudan's precarious water resources. This is done by comparing water availability (in terms of soil moisture surplus/deficit) under baseline conditions with those under climate change conditions, as projected by a combination of models described below. The results illustrate the sensitivity of soil moisture - one important aspect of Kordofan's hydrologic cycle and thus water resources - to climate change.

4.1 Water Resources in Kordofan

Water resources in Kordofan Region are composed of rainfall, surface water and groundwater. Rainfall is the main contributor to both surface water and groundwater recharge. The rainy season in Kordofan is short (May through October), while the dry season extends more than six months. The Coefficient of Variation (CV) of rainfall varies between 15% to 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%. Depending on rainfall is clearly a risky approach but in Kordofan it is unavoidable - the majority of the population practice

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[5] Flow from three streams - Gash, Baraka and Azum - comes to one third of this amount.

traditional rain fed agriculture.

Table 4.1 provides an indication of historic rainfall in the five stations. (For a more comprehensive overview of historic and projected patterns in rainfall, see Chapter 3 and Section One of Volume II.)

4.2 Surface water

Kordofan Region has no permanent surface water. The main seasonal water course (khor) is Abu Habil. This stream originates in the Nuba Mountains and carries water between July and October, with an annual discharge in the range of 132 to 200 million cubic meters. The area surrounding the foothills of the Nuba Mountains slopes gently West to East, from 500 meters above sea level, at a gradient of 2˚ to 3˚. The area between El Dalang and Er Rahad of the khor catchment is drained by many large and small shallow seasonal waterways. After rainfall, water that falls and gathers in the foothills drains through this system of rills and gullies before it collects in the khors which discharge into Abu Habil stream .

In the vicinity of Er Rahad, El Semih and downstream rivers, the topography becomes flatter, the velocity of stream flow is reduced, and suspended material is deposited in alluvial plains. In these areas, water is spread naturally over the terrain. Water that lies stagnant will eventually percolate down through the soil as part of the groundwater recharge process.

4.3 Ground water

At this time, groundwater in Kordofan is mainly used for human consumption and for watering livestock – a central socioeconomic activity in the region. It is also being used increasingly in supplementary irrigation and in cooling systems of the petroleum industry. The storage of water in the aquifers is not sufficient to meet the growing demands of the region: human, livestock, agricultural, and industrial.

The depth of ground water in Kordofan Region varies between 241 and 310 meters. Extraction at these depths can be quite costly. To facilitate an understanding of the groundwater resource in Kordofan, an overview of the system is provided here.

Kordofan has four main aquifers: the Alluvial aquifer, Umm Ruaba aquifer, Nubian sandstone aquifer, and the Basement complex aquifer. Of these four, the Umm Ruaba and Nubian aquifers are considered the most important. A number of basins contribute to the process of drainage and recharge to the aquifers; chief among these are Nahud, Kordofan, and Central Darfur Basin. Major characteristics are summarized in Table 4.2.

Table 4.1: Historical annual rainfall (mm) at selected stations

Year	El Obied	En Nahud	Rashad	Kadugli	Babanusa	Average
1961	446.7	308.0	883.0	614.2	NA	550.5
1962	511.8	443.1	744.5	835.5	NA	633.7
1963	315.8	298.5	898.5	788.4	NA	575.3
1964	544.3	500.5	795.2	650.8	NA	617.6
1965	358.9	472.7	688.1	868.7	NA	577.7
1966	217.4	313.5	939.9	760.6	NA	556.3
1967	267.4	279.2	650.8	742.1	NA	484.9
1968	189.9	334.8	784.1	457.1	NA	431.5
1969	164.2	292.3	710.0	639.6	NA	451.2
1970	261.4	383.8	740.0	566.9	NA	488.0
1971	332.7	245.7	723.5	701.9	NA	500.9
1972	336.9	422.8	620.5	575.4	NA	488.9
1973	293.5	256.9	604.4	468.8	NA	405.9
1974	346.6	387.0	641.1	824.5	478.2	535.5
1975	201.6	379.0	601.7	654.9	460.5	460.1
1976	432.6	286.4	760.8	593.4	491.6	513.0
1977	303.6	317.6	650.2	880.6	445.1	519.4
1978	468.2	391.7	1003.7	740.9	542.7	629.4
1979	284.4	423.8	703.4	736.6	395.9	488.8
1980	364.9	681.0	614.9	523.0	636.4	564.0
1981	312.3	294.4	622.4	782.5	552.9	512.9
1982	201.9	363.1	723.5	561.6	390.5	444.1
1983	351.8	312.2	605.1	655.5	411.6	467.2
1984	161.7	138.9	614.9	469.8	267.3	330.5
1985	218.6	320.9	678.7	606.1	515.1	467.7
1986	375.6	274.7	595.4	666.3	560.1	494.4
1987	226.3	318.0	456.3	525.1	431.3	391.4
1988	346.0	382.4	722.7	611.3	852.1	582.9
1989	267.8	311.4	686.4	831.6	431.5	537.6
1990	170.6	164.6	530.3	511.1	459.9	367.5
1991	204.1	410.5	650.8	1432.1	489.6	637.4
1992	513.8	428.1	864.4	526.4	490.2	564.6
1993	378.7	334.3	631.2	814.9	492.0	530.2
1994	544.7	425.7	603.2	796.3	492.0	572.4
1995	305.8	475.9	574.6	799.8	494.8	529.4
1996	359.3	380.9	518.6	623.0	492.0	474.8
1997	306.1	496.8	544.9	379.4	497.6	443.0
1998	325.3	399.8	747.4	809.7	489.4	550.3
Average	**318.1**	**335.9**	**717.7**	**633.1**	**497.3**	

Table 4.2: Characteristics of Kordofan's basins

Groundwater Basin Name	Groundwater depth (m)	Saturated thickness (m)	Basin area (km2)
Nubian Basins			
Nahud	100-120	150-250	6,798
Central Darfur	25-100	100-350	52,924
Umm Ruaba Basins			
Eastern Kordofan	50-755	100-500	68,392

En Nahud Basin: This basin is an isolated outlier of Nubian Sandstone located in the central parts of Northern Kordofan. The Heidob well field west of Nahud is the most exploited part of the aquifer, where abstracted water is used for the town water supply.

Central Darfur Basin: This basin covers the central part of Darfur and the western area of Northern Kordofan. In the northern part of the basin the water quality is quite good, indicating that the aquifer material here is siliceous and that this area is a zone of recharge. The groundwater moves from the North to Southeast at a speed of 0.3 to 6.0 meters per year.

Eastern Kordofan Basin: The eastern Kordofan Basin covers the area of Kordofan to the north of El Obeid, extending in a southeast direction toward the White Nile. The main recharge to this basin is from the White Nile and from surface flow during the rainy season.

Recharge: The Nubian groundwater is not generally renewable, except on occasions when recharge of the Umm Ruaba aquifer reaches it. The Nubian groundwater aquifer level is not deeper than Umm Ruaba, which means that the extension of the Nubian aquifer comes above Umm Ruaba and accordingly can be recharged.

The recharge, underflow, and abstraction are annual values, whereas basin storage is the water already existing in the aquifer, aside from recharge. Underflow refers to an underground stream passing through the aquifer, which is constantly adding and abstracting water. The exception occurs when the level of the aquifer declines, below the underflow balance, in which case the underflow will tend to replace the shortfall. This, of course, depends on the amount and rate of water extraction.

The basin storage per year in the eastern part of Kordofan (Umm Ruaba aquifer) is 1.71 billion cubic meters per year, and in the Nubian aquifer (Nahud Basin and the extension of Central Darfur Basin), the storage is about 0.083 bcm per year, for a total of 1.793 bcm per year.

Table 4.3: Groundwater potential of the basins

Groundwater Basin Name	Flow (mcm)/yr	Recharge (mcm)/yr	Basin storage (mcm)/yr	Withdrawal (mcm)/yr
Nubian Basin				
Central Darfur Basin	12.8	47.6	79.4	5.6
Nuhad Basin	1.5	15.4	3.6	2.5
Umm Ruaba Basin				
Eastern Kordofan Basin	2.5	15.8	1710	4.5

Note: mcm=million cubic meters

Clearly, groundwater storage is limited and recharge is extremely modest. For this reason, surface water received from rainfall is extremely important in compensating for the deficit. Water resources in the region are, therefore, extremely vulnerable to rainfall storage.

4.4 Water Use

The annual consumption of water per person in Sudan is a mere 500 cubic meters. Though 1000 cubic meters technically exists for consumption, it is currently inaccessible (i.e., has not been harvested, stored or otherwise mobilized for use).

The population of Kordofan, in 1993, was roughly 3,605,300. By 2030 it is projected to be 5,617,360. In the absence of climate change, and under present quantities of accessible water, per capita water consumption will decrease in milestone year 2030 to between 300 and 400 cubic meters. It is expected to worsen further in 2060. These annual per capita allocations drop even further when other forms of consumption such as livestock, irrigation, and industry are factored in.

4.5 Approach to the Analysis

This analysis explored potential changes in water surplus and deficit in soil under conditions of climate change, and thereby drew conclusions about the sensitivity of Kordofan groundwater to climate change.

Temperature and precipitation have a very strong correlation. Temperature is an important factor in the formation of clouds and consequently the cause of precipitation; at the same time it plays a vital role in the mechanism of evaporation. Similarly, precipitation can exert a cooling effect, reducing the effects of temperature. These two factors can determine soil moisture in terms of surplus and deficit, as calculated in a series of steps described below.

Of the water received as rainfall, part evaporates from the ground and is transpired by plants, depending largely on temperature. When soil is fully saturated, excess water either flows as runoff (according to elevation) or infiltrates the soil. This mechanism of percolation provides a level of moisture to the soil and is an indication of groundwater recharge. Water surplus or deficit refers to the depth (in millimeters) to which excess water has penetrated the soil. The soil at each station has its own water holding capacity. Water surplus or deficit measures the degree to which the holding capacity of soil is or is not filled. Surplus is an indication that holding capacity is exceeded and groundwater recharge will take place. Deficit indicates that inadequate soil moisture exists for effective recharge to take place.

4.6 Methodology

First, the projected values of temperature, which were obtained from the three GCMs, are used for computation of PET by using the FAOMET model. The default values of sunshine hours, wind speed, and water vapor pressure were used in the computation. These calculations were done for each station in both milestone years. PET output is then used as input to the FAOINDEX soil/water balance model.

Secondly, FAOINDEX is used to compute the soil/water balance at the five stations. The parameters PET and precipitation (P), soil type, land elevation (in %), water holding capacity (maximum storage of water in the soil), normal rainfall, and water consumed by the green cover *for each station* are inputs to the model. Like values of T, P, PET, and land elevation, water holding capacity also varies from station to station. The outputs of FAOINDEX are soil moisture – interpreted here as water surplus and deficit - and water satisfaction index for plants.

Surplus water means that the soil is fully saturated by rainfall or surface water. This excess water will generally percolate into soil and contribute to groundwater recharge. On the other hand, a water deficit exists when the water received from rainfall and surface water is below the water holding capacity of the soil.

To summarize, this analysis involved the following steps:

- The projected temperature and precipitation are obtained from the three general circulation models (HADCM2, BMRC AND GFDL).
- These parameters of temperature and precipitation - in addition to the default values of sunshine hours, wind speed in meters/sec, water vapor pressure - are processed on dekadal basis to meet requirements of the impact models.
- The FAOMET model package is used for computation of PET.
- The FAOINDEX model is used for computing the soil water balance.

4.6.1 Limitations and Uncertainties

A central limitation in this analysis is that the connection between soil moisture and groundwater recharge in Sudan is not entirely understood and thus, not explicitly quantified. Other factors influence recharge, including surface waterways, but the contribution of these and of percolation through soil to a value of net groundwater recharge could not be undertaken in this phase of activity.

4.7 Water Resource Vulnerability

The findings of this study create a picture of Kordofan that is drier and experiences greater water stress. The values of temperature and precipitation in the climate change scenarios were used to compute water surplus and deficit values in milestone years 2030 and 2060. The results are shown in Tables 4.4 and 4.5 which compare the baseline values of water surplus and deficit to the climate change values. The values of soil moisture in 2060 show less water deficit than in year 2030 for the model GFDL. This situation can be attributed to significantly increased precipitation in the year 2060, projected by this model.

Table 4.4: Average increases in potential evapotranspiration from the three GCMs in 2030 and 2060 (mm)

	Baseline	HADCM2		BMRC		GFDL	
STATIONS	**(1961-1990)**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
El Obeid	3,121	194	532	303	352	341	367
En Nahud	2,726	334	581	416	458	443	421
Rashad	2,700	164	182	98	119	114	234
Kadugli	2,525	338	514	408	434	423	373
Babanusa	2,692	448	654	510	541	530	537

Note:IS92A scenario used; PET used to represent evapotranspiration

Table 4.5: Average decreases in soil moisture from the three GCMs in 2030 and 2060 (mm)

	Baseline	HADCM2		BMRC		GFDL	
STATIONS	**(1961-1990)**	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
El Obeid	-45	-51	-60	-55	-54	-60	-59
En Nahud	-35	-40	-45	-42	-40	-46	-46
Rashad	-9	-13	-18	-15	-16	-16	-15
Kadugli	-5	-24	-29	-27	-27	-27	-25
Babanusa	-24	-32	-42	-38	-40	-37	-34

Note: IS92A scenario used

4.8 Conclusions

A decrease in available water resources will clearly have significant ramifications for Kordofan. The region has in the past been affected by drought, which has led to reduced crop yield, reduced household income, increased migration of nomads and their herds, increased conflict between pastoralists communities and sedentary farmers over land and water, and an increase in displaced people and urban migration. The effect has been greater stress on precarious social systems and on fragile or overburdened ecosystems.

5. Mitigation Options in the Energy Sector

5.1 Introduction

Sudan's ratification of the United Nations Framework Convention on Climate Change (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. This chapter summarizes a national-level analysis of a set of mitigation options in the energy sector.

The purpose of this chapter is to provide an overview of major opportunities for reducing GHG emissions in the energy sector in Sudan. Specifically, the major objectives of the study were as follows:

- Characterize the appropriate range of technologies and measures that can reduce GHG emissions and are also consistent with national development priorities;
- Analyze the impacts of the GHG mitigation measures chosen on net emissions, costs, and local environmental quality; and
- Propose a plan of action for encouraging adoption of the most attractive of the mitigation technologies analyzed.

This chapter focuses on the energy sector only. Mitigation assessment results for non-energy sectors (i.e., land use and forestry) are discussed in a separate report.

5.1.1 Institutional Setting For Energy Planning In Sudan

Planning for the supply of energy takes place in a number of different government organizations in Sudan.

In the mid-seventies, the Ministry of Energy and Mining (MEM) was been established to address energy supply planning issues. Within the MEM, the National Energy Administration (NEA) was established in 1980 to deal with energy planning and coordination in energy sector. Other parts of MEM include the General Petroleum Corporation (GPC), National Electricity Corporation (NEC) and the Geological Research Authority. At the macro-economic level, an energy sector planning unit exists within the Ministry of Finance & Economic Planning.

Several other government institutions are involved in energy planning energy in a way or another but are not organized under the MEM. They include: Energy Planning Section in the Ministry of Finance and Economic Planning, the Higher Council for Environment and Natural Resources of the Ministry of Environment & Tourism, the National Forestry Corporation of the Ministry of Agriculture and Forestry, Energy Research Institute, and the Institute of Environmental Studies.

Electric supply planning in Sudan has historically been a centralized activity, with little if any differentiation between the owner, operator, and regulator of power plants. In recent years, there have been changes in the planning process of the National Electricity Corporation. Private and expatriate companies and investors are permitted to generate and sell electricity. In recent years, energy sector reform has addressed new oil production activities. The Sudanese Petroleum Corporation (SPC) has been established to develop all processes of petroleum. The National

Energy Affairs (NEA) became responsible for energy planning, dissemination of renewable energy technologies, and energy conservation and environment.

These institutions can be classified into the following main categories: Policy and Planning, Energy Supply, Training, Research, and Development and finally Environment (see Table 5-1).

Coordination among these institutions occurs at the Ministry level, particularly during planning for the 5-year Plan. As this was the first climate change project for all institutions involved, a major task in conducting the mitigation analysis was to convene experts from selected agencies to share data sources and identify mitigation appropriate for Sudan's circumstances.

Table 5.1: Sudanese Energy Institutions, 2000

Category	Institution
Policy and Planning	• Ministry of Energy & Mining (MEM) • Sudanese Petroleum Corporation (SPC) • Energy Planning Section in Ministry of Finance & Economic Planning (MFEP)
Energy Supply	• Sudanese Petroleum Corporation • National Electricity Corporation (NEC) • National Forestry Corporation (NFC) • Geological Research Authority (GRA) • Private Sector companies and enterprises
Training, Research & Development	• Energy Research Institute (ERI) • Sudanese Petroleum Corporation • University of Khartoum (UK) • University of Gezira (UG) • Forestry Research Center (FRC)
Environment/Energy	• Higher Council for Environment and Natural Resources (HCENR) • Institute of Environmental Studies • Environmental Research Institute

5.1.2 Current Energy Use Patterns

The year 1995 was chosen as the base year for the analysis because it is also the reporting year for the GHG inventory. The data collection effort in developing the national GHG inventory was used to estimate the total primary energy consumed in Sudan in 1995.

5.1.2.1 Energy Supply Characteristics

As of January 1999, Sudan's proven crude oil reserves are estimated by the government to be between 700 and 900 million barrels, representing between 0.08% and 0.10% of proven world reserves. Its proven natural gas reserves are estimated at 3 trillion cubic feet, representing about 0.06% of proven world reserves, respectively.[6] Until recently, oil exploration has been limited to the central and south-central regions, representing about 15% of the national oil reserves. Plans are underway to begin oil exploration in northwest Sudan, the Blue Nile Basin in southeastern

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[6] Source for proven global reserves is http://www.eia.doe.gov/pub/international/iea98/table81.xls.

Sudan, and the Red Sea area in eastern Sudan. Current crude oil production totals about 210,000 barrels per day and has been rising steadily since the completion of a pipeline in July 1999 linking oil fields in the central region of the country to the Red Sea coast.

Sudan has three oil refineries, with the largest being the 50,000 bbl/d Khartoum Oil Refinery in the Jayli area, 30 miles North of Khartoum. This refinery produces benzene and butane gas for domestic consumption and export, as well as gasoline for local consumption. With its opening in June 2000, Sudan has become self-sufficient in all petroleum products except for jet fuel. A portion of the surplus gas eventually will be available in the production of electricity. The next largest refinery is located in Port Sudan and has a current capacity of 21,700 bbl/d, with plans to expand capacity by 70%. The third refinery is a comparatively smaller facility located in central Sudan near El Obeid with a capacity of 10,000 bbl/d. Sudan has also two topping plants one at Abu Gabra in West Kordofan State with design capacity 2,500 b/day and the other is a private sector one in Khartoum with design capacity 10,000 b/day owned by Concorp International (products include diesel oil, kerosene, naphta, and furnace.

There are plans underway by the Sudan's National Petroleum Company (NPC) to lay pipelines to supply Eritrea and Ethiopia with petroleum derivatives from the Khartoum refinery. If approved, the pipelines would pass through Sudan's Gezira, Sennar, and Gedaref states. NPC is also studying the feasibility of running another pipeline to export crude oil from the Adaryel oil fields in southern Sudan to Ethiopia.

Electric capacity and generation consists of a combination of thermal and hydro facilities as shown in Table 5.2. Technical and administrative losses have been escalating during the period 1990-1995 and power cuts have been quite common. Most of the energy generated in Sudan continues to be hydro-based, though its share has been decreasing recent years, as summarized in Table 5.3. Two interconnected electric grids exist -- the Blue Nile grid and the Western grid. Much of country, however, is not served by the electric grids. Some regions and communities which are outside the two main grids use small-scale diesel-fired plants to generate electricity.

Table 5.2: Electric capacity and generation, 1995

Year	Capacity (MW)	Generation (GWh)	Losses (%)
Hydro	308	970	
Oil Steam	165	630	
Gas Turbine	66	70	
Diesel	188	190	
Total	**727**	**1,865**	**28%**

Table 5.3: Electric generation shares 1990-1995

Year	Hydro (GWh)	%	Thermal (GWh)	%	Total (GWh)
1991	1,038	66	537	33	1,576
1992	1,002	65	533	35	1,535
1993	1,091	67	542	33	1,633
1994	1,121	60	737	40	1,858
1995	972	52	892	48	1,864

5.1.2.2 Energy Demand Characteristics

Table 5.4 shows the structure of primary energy consumption by fuel type for 1995. Most energy (338.78 million GJ, or about 85%) is from biomass. Figures 5.1, 5.2, and 5.3 summarize 1995 energy use by sector.

For biomass-based fuels (i.e., wood fuel, charcoal, agricultural residues, bagasse), the household sector is the dominant consumer, accounting for 74% of overall consumption. However, the commercial sector with its growing service orientation, is also a significant user of biomass fuels.

Table 5.4: Primary Energy Consumption, 1995

Fuel Type	Energy Use (million GJ)
Gasoline	8.20
Kerosene/Jetfuel	2.35
Diesel/Gas Oil	32.85
Residual/Fueloil	15.09
LPG/Bottled Gas	0.86
Firewood	175.79
Charcoal	132.26
Bagasse/Other	30.73
Total	398.23

Figure 5.1:Total energy Consumption by sector, 1995

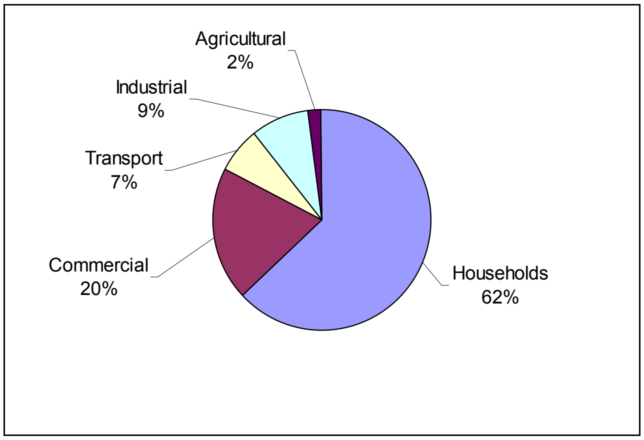


Figure 5.2: Petroleum-based consumption by sector, 1995

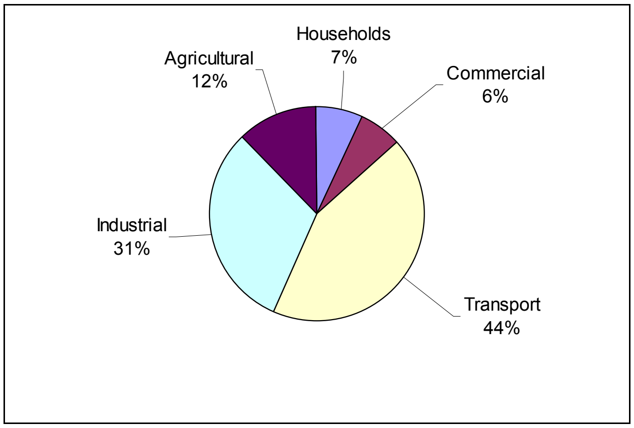
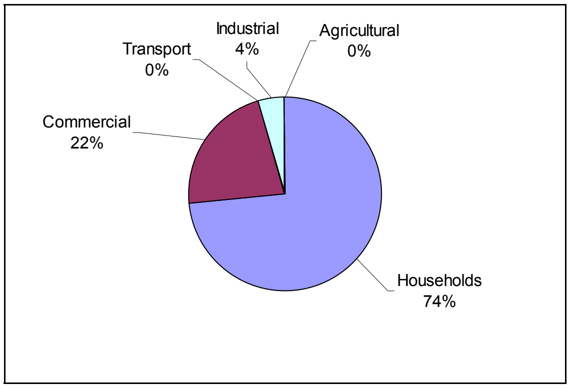


Figure 5.3: Biomass-based consumption by sector, 1995



For petroleum-based fuels (e.g., diesel, LPG, etc), the majority of these products are consumed in the transportation sector, which represents over 40% of total consumption. The agricultural sector is also a major consumer of petroleum products, mostly in the form of diesel fuel that is used in irrigation pumps.

Total energy consumption across all demand sectors is estimated to be about 404 million GJ (see Table 5.5). The household sector consumes the largest amount of energy, about 254 million GJ, or almost 63%. The commercial is next largest consuming sector, accounting for about 20% of overall energy use. By comparison, the transport, industrial, and agricultural sectors are small energy consumers in the base year, accounting for only 7%, 9%, and 2% of total energy use, respectively. Details of energy use in individual sectors are discussed in the following subsections.

Table 5.5: Summary of energy demand in Sudan, 1995 (million GJ)

Fuel Type	Household	Commercial	Transport	Industrial	Agricul	Total
Electricity	2.88	0.03	0.00	1.84	0.62	5.37
Gasoline	0.00	0.00	8.20	0.00	0.00	8.20
Kerosene/Jetfuel	0.25	0.00	2.10	0.00	0.00	2.35
Diesel/Gas Oil	0.73	1.19	17.40	6.23	7.30	32.85
Residual/Fueloil	0.00	2.79	0.08	12.22	0.00	15.09
LPG/Bottled Gas	0.80	0.06	0.00	0.00	0.00	0.86
Firewood	140.71	26.40	0.00	8.68	0.00	175.79
Charcoal	83.33	48.93	0.00	0.00	0.00	132.26
Bagasse/Other	24.81	0.00	0.00	5.92	0.00	30.73
Total	253.51	79.40	27.78	34.89	7.92	403.50

In 1995, Sudan’s end use consumption level of electricity was comparatively small, about 5.4 million GJ, compared to overall energy consumption. As shown on Table 5.5, the household sector is the major consumer of electricity (53% of total demand), with substantially less electricity being used in the industrial and commercial sectors.

5.1.3 Current Greenhouse Gas Emission Patterns

The previously developed greenhouse gas emissions inventory was used as a starting point for this mitigation analysis. The IPCC methodology (revised 1996 guidelines) was used to develop this inventory and include the most important sources and sinks for present and future GHG emissions. The range of energy sector GHG mitigation options are a function of the source for these emissions, which are summarized as follows:

- Crude oil extraction (from Unity, Muglad, Heglig, and other fields);
- Transformation of crude oil into refined oil products;
- Transformation of fuels (heavy fuel oil and diesel) into electricity;
- Transformation of fuel wood into charcoal;
- Distribution losses (electric grid and pipeline); and
- Sectoral end use consumption (e.g., transport, industry, etc).

Total emissions of carbon dioxide and methane associated with fuel combustion and land use change are summarized in Table 5.6, and clearly show the dominance of the traditional energy sector in which the combustion of biomass (fuel wood, charcoal, agricultural residues) accounts for over 80% of total energy-related carbon dioxide emissions.

Table 5.6: GHG emissions from fuel combustion and land use change, 1995 (Gg)

		Carbon Dioxide			Methane		
		Fossil	**Biomass**	**Total**	**Fossil**	**Biomass**	**Total**
Energy Industries		1,027	0	1,027	0.0	0.0	0.0
Manufacturing Industries and Construction		586	830	1,416	0.0	0.4	0.5
Transport	Domestic Aviation	158	0	158	0.0	0.0	0.0
	Road	1,726	0	1,726	0.0	0.0	0.0
	Railways	30	0	30	0.2	0.0	0.2
	National Navigation	9	0	9	0.0	0.0	0.0
	Pipeline Transport	0		0	0.0	0.0	0.0
Other	Commercial/Institutional	5	3,235	3,240	0.0	9.2	9.2
Sectors	Residential	62	17,871	17,933	0.0	53.5	53.5
	Agriculture/Forestry/ Stationary	1	-6,360	-6359	0.0	0.0	0.0
	Fishing Mobile	549	0	549	0.1	0.0	0.1
Other (not elsewhere specified)		174	0	174	0.0	86.0	86.0
Total		4,328	15,577	19,904	0.4	149.1	149.5
Total National Emissions		4,501	15,577	20,077	0.4	1984.0	1985.0
Energy share of total national emissions		96%	100%	99%	100.0%	7.5%	7.5%

Source: Sudan Inventory Assessment

Net CO2 emissions for biomass resources need to be mentioned at this point. It has been reported in the official inventory as a "memo" item and is reported separately in the table below. Total carbon dioxide emissions from forest and grassland conversion equal 28,714 Gg (of which 21,936 Gg is due to combustion of biomass) while the total removal of carbon dioxide by sinks is equal to 13,138 Gg. The resulting net emission amount of 15,177 Gg of carbon dioxide highlights the deforestation problem in Sudan.

When carbon dioxide emissions from biomass combustion are counted as zero (i.e., the IPCC recommendation), the energy-related CO2 emissions are about 22% of total national carbon dioxide emissions. When carbon dioxide emissions from biomass combustion are counted, the share is considerably larger, 63%. Nitrous oxide and carbon monoxide are also emitted from the energy sector, but to a much lesser degree. These levels are very small relative to the emissions of industrialized countries.

5.1.4 Key Assumptions

In preparing the mitigation plan for Sudan, several assumptions regarding future demographic and economic patterns were made. These are summarized in the following sections.

Demographic growth

The rate of population growth in Sudan is one of the highest in the world. Estimates of recent population growth have ranged from 2.5 to 2.6 percent per year according to the last population census in Sudan in 1993. In consultation with analysts from the Statistics Bureau, the mitigation team has assumed that these growth rates will continue (at 2.6 percent per year) through 2005, declining slowly thereafter. The assumptions used for population growth rates are summarized in Table 5.7 below.

Table 5.7: Demographic growth assumptions

Period	Growth Rate (%/year)
1995 to 2005	2.6
2006 to 2010	2.4
2011 to 2015	2.2
2016 to 2025	2.0

In addition, it is not expected that the average household size (6 persons per household) in Sudan will decrease, resulting in growth in the number of households that keeps pace with the growth in population.

Economic growth

Sudan has become more engaged in the global economy over the past several years and it is assumed that this trend will continue and intensify. Since the end of 1999, Sudan has signed various trade and investment agreements with Saudi Arabia, Bahrain, Iraq, Kuwait, Ethiopia, and Syria. At the same time there are expectations that foreign investments in the oil, gas, and petrochemical industries, particularly from Malaysia, will soon exceed $1 billion. In February of 2000, Sudan opened its Red Sea Free Trade Zone which is intended as an encouragement to direct foreign investment. And, in March of 2000, the government publicly repeated its desire to join the World Trade Organization.[7]

At the present time, however, the Sudanese economy is centrally controlled. The public sector dominates heavy industries, including cement and sugar manufactures, oil refining, and gas treatment and transport. The private sector is typically responsible for activities in light industry, as well as in the commercial sector. In recent years, there have been some joint public/private economic ventures.

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[7] US Energy Information Administration, 2000. *Sudan,* November.

The gross domestic product (GDP) in the country grew at an average rate of 6.3 %/year during the period between 1990-1995. The overall assumption is that economic growth in Sudan will continue its upward trend, though at a slower pace. Judgment was used to decide upon appropriate growth rates for each subsector grows considered in the analysis.

Fuel prices

Assumptions were made regarding changes in fuel prices over the period covered by this mitigation assessment. Table 5.8 summarizes average national prices and growth rates for the various energy resources used that are expected to be used in Sudan during period from 1995 to 2025.

It was generally assumed that the real escalation in fossil fuel prices in Sudan would change at the same rate as international prices for crude oil. Assumptions as to trends in international crude oil prices were derived roughly from oil price forecast data for 2000 to 2020 that are presented in the United States Department of Energy's International Annual Energy Outlook 2000 Forecast Comparisons.

Table 5.8: Fuel price assumptions, 1995

Energy Resource	Price (1995 US$/GJ)	Average Growth rate (%/year)
Charcoal	4.7	0.00%
Electricity	17.1	0.00%
Gasoline	17.3	1.52%
Diesel	7.6	1.52%
LPG	13.0	1.52%
Kerosene	8.5	1.52%
Fuelwood (urban)	3.3	0.00%

5.1.5 Guide To Remainder of this Chapter

The remainder of this chapter is organized as follows:

- **Section 5.2** presents an overview of the methodology used, including major steps in the analysis, the modeling approach used, and identification of mitigation options;
- **Section5.3** provides details concerning the demand side analysis, including energy and GHG projections with and without mitigation options;
- **Section 5.4** provides details concerning the supply side analysis, including energy and GHG projections with and without mitigation options;
- **Section 5.5** provides a synthesis of cost and offers recommendations for follow up analysis;
- **Appendices** provide a tabular summary of the inputs and outputs of the analysis.

5.2 Methodology

The analysis period is from the 1995 base year through the year 2025. Two plans are considered: a "Base Case" assuming business-as-usual assumptions, and a "Mitigation Case", with a set of measures that reduce GHG emissions. The Long range Energy Alternatives Planning System model (LEAP) was used to integrate demand and supply mitigation options and calculate GHG emission reductions and associated costs.

5.2.1 Analytical Steps

The steps involved in the analysis are briefly outlined below.

- **Establish the Base Case:** Energy demand for the Base Case (business-as-usual case) started with collecting and assembling historical energy use data. The team also reviewed existing demand forecasts, as well as economic, demographic, industrial productivity, and other statistics. The mitigation team also reviewed the results of existing (limited) end-use surveys in the residential sector. After compiling the information, an energy demand forecast was prepared using a combination of end-use, econometric, and trending methods.
- **Identify Appropriate Demand-Side Mitigation Options:** The team prepared a list of technologies and measures that could be used to reduce emissions of greenhouse gases in the Sudanese energy sector.
- **Identify Appropriate Supply-Side Mitigation Options:** The mitigation team reviewed options for future supplies of electricity that reduce carbon emissions. This supply-side review focused on the electric sector and started with a basic set of generation options, ranging from oil- and gas-fired plants in different configurations to renewable-energy generation options such as wind and solar power.
- **Establish a Mitigation Case:** For each of the demand and supply side mitigation options regarding, targets for energy savings and incremental renewable energy use were established based on achievable potential relative to a set of socioeconomic constraints.
- **Estimate the costs and benefits of the Mitigation Case:** Using the LEAP model, energy savings, carbon reductions, and costs for the Mitigation Case were calculated.

5.2.2 Energy Demand Analysis Approach

Five major energy-consuming sectors were considered in the analysis. Their major characteristics are as follows:

- **Households sector:** rural and urban households using energy for cooking, lighting, refrigeration, space cooling, and other end uses;
- **Commercial sector:** business and governmental establishments using traditional and commercial energy resources is buildings;
- **Transportation sector:** vehicles using commercial energy for transport of passengers and freight;
- **Industrial sector:** facilities for the manufacture of a variety of products, using mostly commercially available energy, and
- **Agricultural sector:** irrigated and mechanized rain fed farms using commercially available energy resources for water pumping and miscellaneous farm operations.

Energy consumption levels were obtained from several basic methods, as follows:

- **Official records:** for some sectors, good quality data was available (e.g., electric generation). This was also true for certain demand categories (e.g., diesel fuel sold);

- **Expert judgment:** for some end uses, expert judgment regarding was used to determine annual usage levels (e.g., kg of firewood used per meal per household); and
- **GHG inventory:** data was compared to the energy consumptions statistics compiled during the development of the national GHG inventory.

Where discrepancies were evident among these sources, the mitigation team sought to resolve these through either additional research or other data/assumption quality checks.

For projecting energy consumption into the future, the mitigation team first examined the viability of using energy demand forecast methods – trending, econometric, and end use. It was recognized that the approach involves statistical analyses, and moreover each, either implicitly or explicitly, involves assumptions.

While it was recognized that an end-use forecast would provide the most insight to the factors that drive changes in electricity consumption, in many cases the data available did not permit full end-use forecasting. In addition, though it would have been desirable to produce a forecast for energy use that was differentiated geographically by region within the country, the combination of lack of data and lack of time made such an effort impractical for this assessment.

The approach taken in using historical data and in modeling future energy consumption was therefore to use an end-use approach as much as possible, together with econometric and trending methods, plus considerable application of professional judgment on the part of the mitigation team. Training in this composite approach was provided to the team through international expert assistance. In addition to this approach lending itself well to the modeling framework used by LEAP, it was felt that it offered several additional advantages as follows:

- It was flexible and could be tailored to real data constraints in Sudan;
- It could quite detailed where data was available, hence providing information in a transparent manner for future updates to the mitigation analysis;
- It would not be technically complex, requiring mostly simple arithmetic to carry out;
- On the electric side, this approach could provide an integrated forecasts of both energy and peak power demands;
- The assumptions used would be relatively easy to follow, to check, and to revise as new data become available; and
- This approach would make it more straightforward to estimate the impacts of energy-efficiency options.

Several steps were involved in compiling the end-use energy demand forecast. The first step was to collect consumption data in sufficient details to enable a division of historical energy use (1990 to 1995) by consuming sector. The next step was to collect "activity" information—such as the number of households, sectoral economic activity, or industrial output in physical units—which corresponded, at least roughly, to the sectoral breakdown in fuel and electricity data.

Values for historical activities by sector or sub-sector (for example, tonnes of cement production at Sudan production facilities) and computed electrical energy intensities (for example kWh per tonne of cement produced) were used as a starting point. With these historical data as a basis, the combination of forecast methods described above was used to estimate values for activities and intensities at five-year intervals from 2000 to 2025.

These values (and annual values calculated by interpolation in the LEAP model) were multiplied together to provide individual forecasts, by year, for each sector and sub-sector (or end-use). The components of the forecast were then added together to provide a summary of electrical energy demand, which was used as the basis for peak power demand forecasts. Only one forecast scenario was developed, which essentially extrapolates recent trends in many sectors, and incorporates, in some industrial sub-sectors, the current industrial development plans in the responsible ministries.

5.2.3 Energy Supply Analysis Approach

There are two major components of supply planning: the review and evaluation of individual energy supply options (i.e., oil & gas, and electricity), and the preparation and evaluation of supply plans. This mitigation analysis focused exclusively on opportunities electric supply sector, as a) this sector is expected to see the largest growth during the next 30 years and b) the electric system will switch from a predominantly hydro-based system to one that relies heavily on fossil fuels.

The review of electricity supply options consisted of:

- Development of a listing of all possible applicable electricity supply options and related infrastructure;
- A review of the attributes of each option; and
- The selection of the more promising options for analysis in this mitigation assessment.

From a technical point of view there are often dozens, if not hundreds, of different supply options and configurations that could be used in Sudan. The goal of this supply review process is not to explore each possibility but to, through consensus process among the members of the Mitigation Team, develop a plan that is both cost-effective and is able to significantly mitigate GHG emissions.

Broadly speaking, the general supply planning approached used in this GHG mitigation analysis included four major tasks as outlined below:

- Characterize the existing electric supply system.
- Characterize new supply options, both fossil and renewable.
- Represent energy savings from demand-side mitigation measures and generate the Mitigation Case electric expansion plan.

After completing the steps above, results were synthesized in order to identify the cost and environmental impacts associated with the plans. The supply planning process was an iterative process between the mitigation team and the international backstop consultants. Extensive discussions and consultations were held on the many technical inputs and assumptions needed to run the LEAP model.

5.2.4 Identification and Screening of Mitigation Options

The overall steps involved in identifying energy efficiency measures on the end use side with the greatest GHG reduction potential were as follows:

- Identify potential opportunities within consumer end-user groups;
- Evaluate GHG reduction potential of a set of energy efficiency measures;
- Select the most promising set of measures for further analysis;
- Evaluate the costs and energy savings benefits of the selected measures; and
- Incorporate the selected measures into a mitigation plan for Sudan.

The first step in the evaluation process was to "brainstorm" among the mitigation team in order to develop a list of potential opportunities for applications of energy efficiency measures within consumer end-user groups in Sudan, and renewable/efficiency measures on the supply side. The process of identifying opportunities was an informal one based on input from international consultants, a review of energy end uses in Sudan provided during the demand forecasting effort, and assessment of the practicality of supply/demand side opportunities under conditions in Sudan. The potential opportunities arrived at by this process are considered a "first cut" and clearly not exhaustive.

5.2.4.1 Opportunities in the Household Sector

Within the household sector, the Mitigation Team identified the following major opportunities to either use energy more efficiently or to use lower or zero carbon-emitting fuels.

- **Cooking:** switching to the use of LPG in the place of inefficient woodstoves and charcoal stoves in rural and urban areas. Also, switching to the use of solar cookers units in rural areas that have limited access to biomass supplies.
- **Lighting**: Encourage continued use of fluorescent lamps, improve fluorescent fixtures and ballasts where they are in use; use compact fluorescent lamps (CFL) in place of incandescent lamps, possibly encourage widespread use of CFLs through establishment of a joint-venture CFL factory.
- **Space Cooling:** Introduce more efficient air conditioning units in urban areas, use load controllers to reduce peak power use. Introduce evaporative coolers to reduce peak power use.

5.2.4.2 Opportunities in the Commercial Sector

Within the commercial sector, the Mitigation Team identified the following major opportunities to use energy more efficiently.

- **Lighting**: Encourage use of improved fixtures and ballasts, use of compact fluorescent lamps in place of incandescent lamps, use of occupancy sensors to turn off lights in unoccupied rooms; use of energy-saving dimming and daylighting systems (particularly in newer buildings), and use of high-efficiency exit signs (though exit signs are of low wattage, they typically operate for 24 hours per day).

- **Space Cooling:** Introduce more efficient air conditioning units, use load controllers to reduce peak power use.

5.2.4.3 Opportunities in the Industrial Sector

Within the industrial sector, the Mitigation Team identified the following major opportunities to use energy more efficiently.

- **Motive Power:** Electric improvements, including higher efficiency motors, better sizing of motors to improve the energy efficiency of the processes that they operate, better design of process flow, and variable speed motor controllers.
- **Efficient Boilers:** Higher-than-standard efficiency boilers for use in variety of medium to large industries.

5.2.4.4 Opportunities in the Transport Sector

Within the transport sector, the Mitigation Team identified the following major opportunities to use energy more efficiently.

- **Passenger transport:** Introduce fleet vehicles with higher fuel economy in public sector light duty and heavy-duty fleets and private sector taxis.

5.2.4.5 Opportunities in the Agricultural Sector

Within the agricultural sector, the Mitigation Team was not able to identify major opportunities to use energy more efficiently.

5.2.4.6 Opportunities in the Electric Sector

The first step in evaluating supply side opportunities was the development of a short list of potential opportunities appropriate in Sudan (see Table 5.9 for a list of supply side options that were considered and selected). As with the identification of energy efficiency opportunities, the process of identifying opportunities is clearly not exhaustive. In assembling this list, measures were selected that a) were appropriate for implementation in the Sudanese context and b) offered the most cost-effective opportunities to achieve GHG reductions.

While mitigation options in the electric sector focused on both fossil and renewable resources, the process of including renewable resources is a supply expansion plan was considerably more complicated due to the fact that good renewable energy resource assessments are scarce for Sudan. Moreover, for those assessments that do exist, the potential is usually expressed as annual averages, which are not necessarily good indicators of the performance of renewable technologies. Additional details emerging from site-specific siting studies will be needed to characterize the precise potential for providing electric power. Nevertheless, the following subsections summarize what information is known about the country's renewable resource base.

- **Solar Resources**: There are high levels of solar radiation throughout Sudan for most of the year. According to the NEA and the Ministry of Energy and Mining, the potential for development of solar thermal energy systems is quite large. The total annual solar radiation on leveled surfaces is estimated at 6.9 joule/m^2 /year in the South, to 10.1 joule/m^2/year in the North and increase to the far North.

Table 5.9: Mitigation Opportunities in the electric supply sector

Option	Description	Status
Fuel switching at existing units	Switch from heavy fuel oil to natural gas	Not Selected
Efficiency improvements	Lower the heat rate at existing units	Not Selected
Repowering	Retrofit existing units to switch from oil to natural gas	Not Selected
Early retirement of inefficient units	Prematurely retire inefficient oil-burning units and replace with natural gas-fired units	Not Selected
Intermittent renewable energy capacity	Add zero-carbon renewable resources to the electric system	Selected
Advanced fossil capacity	Add advanced fossil capacity that is both more efficient than conventional alternatives and/or has a lower GHG intensity	Selected
Transmission and distribution improvements	Install new transformers, substations, and other components to reduce line losses	Not Selected
Dispatch changes	Modify dispatch of existing units to reduce GHG emissions	Not Selected
Lower electric generation levels	Reduce growth in electricity demand through demand side efficiency measures	Selected (demand side)
Offset GHG emissions elsewhere	Reforestation	Not Selected

- **Wind Resources:** There is good potential along the Red Sea. A summary of estimated wind energy potential is presented in Table 5.10 below. A 6 MW wind farm project is now starting in the Dongola area in northern Sudan and is scheduled to go on line in the year 2001.

Table 5.10: Wind Energy Potential in Sudan

Met Station	Region	Annual Wind energy intensity kWh/m^2
Abu Neiama	Central Sudan	924
Wad Madani	Central Sudan	1248
Atbara	Northern Sudan	547
Abu Hamad	Northern Sudan	1761
Dongola	Northern Sudan	5067
Wadi Halfa	Northern Sudan	1498
Aldamazeen	Southeast Sudan	164
Algenina	Western Sudan	1157
Alobied	Western Sudan	605
New Halfa	Eastern Sudan	668
Port-Sudan	Eastern Sudan	1078

Source: Ministry of Energy and Mining, 1992

- **Biomass Resources**: Sudan is quite limited in sustainable biomass sources that could be used for large-scale electricity generation. This resource was not considered further in the renewable candidate electric supply plan.

- **Hydro Resources**: Hydropower provides a significant share of overall electricity production in Sudan. There is potential for additional hydro capacity in the amount of 34.3 MW in the least level and 54.9 MW in maximum level.

In light of the above factors, GHG mitigation opportunities focused on wind and solar thermal technology.

5.3 Energy Demand Analysis

While there are several steps to assure a thorough consideration of demand side GHG mitigation measures, this is a data-intensive process. Given the lack of good end-use data and other quantitative information from the MEM in Sudan, and coupled with a tight time-frame for completing the analysis, the Mitigation Team focused on evaluating the selected high-priority measures identified in the previous chapter.

Results of the mitigation analysis are presented by source of emissions. For this reason, the demand sector results only report fuel combustion in end uses. Carbon dioxide emissions associated with electricity use are accounted for in the electric sector.

5.3.1 Household Sector

5.3.1.1 Current Energy Patterns

In 1995 there were about 4.7 million households in Sudan consuming a total of nearly 254 million GJ. Major subsectors and energy end uses are depicted in the demand tree in the Annex to this Chapter. Table 5.11 summarizes energy use in 1995. As seen in this table, energy consumption was dominated by the cooking end-use in the rural non-electric sector (about 98%).

Most of the energy consumed in the household sector is in the form of biomass (firewood and charcoal), with LPG and diesel and kerosene taking up minor shares. Electricity is used in urban areas and represents less than 3% of total energy consumed in the household sector of Sudan.

Table 5.11: Structure of household energy demand, 1995 (million GJ)

Subsector	End Use	Energy Use (GJ)
Urban-Electric	Other-Enduses	0.73
	Lighting	0.25
	Refrigeration	2.13
	Cooking	46.64
	Air Cooling	0.20
	total	49.95
Urban-Nonelectric	Cooking	39.73
	Lighting	0.03
	total	39.76
Rural-Electric	Other-Enduse	0.03
	Refrigeration	0.22
	Lighting	0.02
	Cooking	3.45
	total	3.72

5.3.1.2 Key Assumptions Driving Future Developments

There are several assumptions, decided upon outside the forecast itself, that to a large extent "drive" forecasted energy demand in Sudan. A general assumption underlying the analysis is that there is an improvement in the overall economic condition in the country. Specific assumptions as to population and household growth are summarized below.

The population rate of growth slows over time according to the following assumptions: 2.6%/yr between 1995 and 2005; 2.4% between 2006 and 2010; 2.2% between 2011 and 2015; and 2.0%/yr between 2016 and 2025.

There is significant urban migration to major cities like Port Sudan, Khartoum/Omdurman, El Obeid, En Nahud, and other urban centers.

Life style changes result in a gradual switching away from traditional fuels like firewood (and especially) agricultural wastes to commercial fuels like LPG and electricity.

Fuel price is stable in real terms for biomass resources (urban firewood and charcoal) and increases for fossil fuels and electricity.

Government policies encourage electricity consumption in all economic sectors.

Government policy encourages greater LPG use and lesser biomass use.

5.3.1.3 Base Case GHG Emission Projections

Carbon dioxide emissions in the household sector between 1995 and 2025 are summarized in Table 5.12. Overall, non-biogenic carbon dioxide emissions from the household sector are dominated by electricity-related emissions which increase from about 386 thousand tonnes to 7,223 thousand tonnes, or about 10.3%/year. In contrast, carbon dioxide emissions from combustion of fossil fuels in end uses increase from about 128 thousand tonnes to 517 thousand tonnes, or about 5%/year. The emissions from both LPG and kerosene (for lighting) increase substantially, an 8-fold and 5-fold increase, respectively. This is due to the increasing urbanization assumed and the wider availability of these energy resources, even though shares remain small compared to biomass. Carbon dioxide emissions from the combustion of traditional fuel sources dwarf those from fossil resources by a factor of 60. This emphasizes the continued expected dominance of these traditional fuels in the Sudan household energy system, particularly for the rural non-electrified sector.

5.3.1.4 Policies and Measures

The cost and performance of energy efficiency technologies in the household sector was obtained from international sources, as noted in the Annex. Targets were established using the Mitigation Team's judgment assuming an aggressive program to achieve GHG reductions. All measures were assumed to phase-in from a start year in 2005 to full penetration in 2025. Brief descriptions of each of the energy efficiency measures are provided below. Each of the subsections provides an overview of a) the technology itself, b) potential program approach, c) possible impediments to implementation in Sudan, d) a tabular summary of the cost and performance characteristics, including pertinent financial costing assumptions, and a summary of the penetration targets for the technology.

Table 5.12: Base Case carbon dioxide emissions from the Household sector

	Carbon dioxide Emissions (thousand tonnes)									
	Fossil fuels					Biomass Fuels				
	1995	2005	2015	2025	Growth	1995	2005	2015	2025	Growth
Subsector										
Urban-electrified	102	185	267	325	4%	4,470	7,380	8,980	7,460	2%
Urban-nonelectrified	11	24	38	50	5%	3,840	3,640	3,260	2,690	-1%
Rural-electrified	0	3	12	32	20%	330	1,540	3,240	5,580	10%
Rural-nonelectrified	14	43	77	109	7%	15,658	16,239	16,152	15,052	0%
Total	128	256	393	517	5%	24,298	28,799	31,632	30,782	1%
Fuel type										
LPG	56	140	259	424	7%	-	-	-	-	-
Diesel	54	79	72	0	-100%	-	-	-	-	-
Kerosene	18	37	62	92	6%	-	-	-	-	-
Firewood	-	-	-	-	-	12,660	12,590	11,900	10,370	-1%
Charcoal	-	-	-	-	-	8,110	12,850	16,730	17,990	3%
Agricultural wastes	-	-	-	-	-	2,818	2,679	2,402	1,972	-1%
Urban firewood	-	-	-	-	-	709	686	608	455	-1%
Total	128	256	393	517	5%	24,297	28,804	31,640	30,787	1%
From electricity	388	2,098	3,427	7,664	10.5%	-	-	-	-	-

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

- **Target Consumer Group:** Residential consumers, urban, and rural.
- **Potential Program Approach/Implementation Strategy:** 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.
- **Possible Impediments to Implementation in Sudan:** 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.
- **Cost and Performance:** The costs and energy savings potential of this technology is summarized in Table 5.13.
- **Targets:** In the year 2025, the use of LPG in the urban non-electric subsector 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 subsector, LPG use doubles, from 25% to 50%. Details of the phase-in schedule for this technology are summarized in the Annex.

Table 5.13: Switching from charcoal/wood to LPG in the household sector

	Units	
Lifetime	Years	15
Real Discount Rate	Percent	9%
Cost of LPG canister	$/unit	0.385
Average traditional cooker efficiency	%	15%
Average LPG cooker efficiency	%	30%
Annual traditional cooking energy use	GJ/HH-yr	22.25
Annual LPG cooking energy use	GJ/HH-yr	11.13
Annual Energy Savings	kWh	11.13
Inc. O&M Cost	$	0
Inc. Administrative cost	$	0
Inc. Ann. Cap Cost	$	0.044
Cap Recovery Factor		0.114
Cost of saved energy	$/GJ	0.0039
Cost per unit	$/HH	0.0438

Solar Cookers for Cooking: Cooking with biomass fuels is a significant end-use in Sudanese households. The use of solar cookers can help to reduce pressures on Sudanese biomass stocks and represents a reliable source of domestic energy.

- **Target Consumer Group:** Residential consumers, rural only
- **Potential Program Approach/Implementation Strategy:** One of the major policy areas of the Ministry of Energy and Mining 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 also participates in training of small entrepreneurs in manufacturing solar boxes for cooking purposes, and encourages the manufacture of solar collectors for utilization in community cooking in prisons, camps, etc.
- **Possible Impediments to Implementation in Sudan:** 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.
- **Cost and Performance:** The costs and energy savings potential of this technology is summarized in Table 5.14.
- **Targets:** In the year 2025, the use of solar cookers in the rural electric subsector 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 the Annex.

Efficient Lighting: Lighting is a significant end-use in 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—can help to reduce lighting energy and peak power use.

Table 5.14: Switching from charcoal/wood to solar cookers

	Units	
Lifetime	Years	15
Real Discount Rate	Percent	9%
Traditional charcoal/wood cooker cost	$/unit	0
Solar cooker Cost	$/unit	250
Annual charcoal/wood use per unit	GJ/hh-yr	18.4
Annual solar cooker biomass fuel use per unit	GJ/hh-yr	0
Annual Energy Savings	GJ	18.4
Inc. OM Cost	$	0
Inc. ADM Cost	$	0
Inc. Ann. Cap Cost	$	28.5
Cap Recovery Factor		0.114
Cost of saved energy	$/GJ	1.546
Cost per unit	$/HH	28.4539

- **Target Consumer Group:** Residential consumers, urban.
- **Potential Program Approach/Implementation Strategy:** 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 electric utilities.

  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%) 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.
- **Possible Impediments to Implementation in Sudan:** 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.
- **Cost and Performance:** The costs and energy savings potential of this technology is summarized in Table 5.15.

Table 5.15: Compact fluorescent light bulbs

	Units	

Lifetime	Years	2		
Real Discount Rate	Percent	9%		
		Std Eff	Lower Cost	Higher Cost
Annual Energy Usage	kWh	58.4	13.2	13.2
OM Cost	$	0	0	0
ADM Cost	$ per participant	0	0	0
Capital Cost	$	7.2	12	22.5
Annual Energy Savings	kWh	0	45.2	45.2
Inc. OM Cost	$	0	0	0
Inc. ADM Cost	$	0	0	0
Inc. Ann. Cap Cost	$	0	2.50	7.98
Cap Recovery Factor		0.522		
Cost of saved energy	$/kWh	N/A	0.0554	0.1765
	$/GJ	N/A	15.3859	49.0424

- **Targets:** In the year 2025, the use of CFLs in the rural electric subsector 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%. Details of the phase-in schedule for this technology are summarized in the Annex.

Evaporative Coolers: Higher-than-standard efficiency evaporative air coolers for residential use as a substitute for air conditioners.

Target Consumer Group: Residential consumers, urban.

Potential Program Approach/Implementation Strategy: 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.

Possible Impediments to Implementation in Sudan: The capability of Sudanese industry to manufacture air coolers is currently limited, so imports must be relied upon in the short term. As with the efficient air conditioner option, 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.

Cost and Performance: The costs and energy savings potential of this technology is summarized in Table 5.16.

Targets: In the year 2025, the use of evaporative coolers in the urban electric subsector 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. Details of the phase-in schedule for this technology are summarized in the Annex.

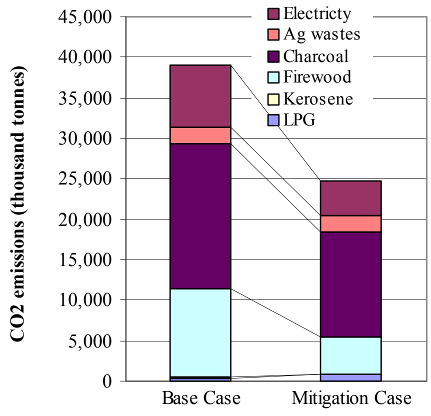
Table 5.16: Evaporative coolers

	Units			
Lifetime	Years	10		
Real Discount Rate	Percent	9%		
		Std Eff	Lower Cost	Higher Cost
Relative Efficiency		100%	82%	78%
Annual Energy Usage	kWh	1500	1230	1170
OM Cost	$	20	15	10
ADM Cost	$ per participant	0	0	0
Capital Cost	$	413	478	513
Annual Energy Savings	kWh	0	270	330
Inc. OM Cost	$	0	-5	-10
Inc. ADM Cost	$	0	0	0
Inc. Ann. Cap Cost	$	0	9.29	14.30
Cap Recovery Factor		0.143		
Cost of saved energy {	$/kWh	N/A	0.0159	0.0130
	$/GJ	N/A	4.4161	3.6160

5.3.1.5 Mitigation Analysis Results

Carbon dioxide emissions in the household sector in 2025 are summarized in the Figure 5.4. While total carbon dioxide emissions decrease by nearly 35% in 2025 relative to what they would have been in the Base Case, it is important to note that much of this reduction is associated with the growing shift away from traditional fuels for cooking to the use of LPG, particularly in the urban electrified subsector. In fact, emissions from fossil fuel combustion (LPG and kerosene) almost doubles by 2025. Yet, even with major fuel switching to LPG, the annual per capita household emissions from fossil fuels remain still quite small, only about 90 kg/per capita in 2025.

Figure 5.4: CO2 reductions by fuel in the Household Sector, 2025



	Base Case	Mitigation Case
Electricty	7,664	4,334
Ag wastes	1,972	1,972
Charcoal	17,990	13,020
Firewood	10,825	4,460
Kerosene	92	92
LPG	424	844

5.3.2 Commercial Sector

5.3.2.1 Current Energy Patterns

In 1995, commercial sector GDP totaled about US $7.8 million. Energy consumption equaled about 79 million GJ. Major subsectors and energy end uses are depicted in the demand tree in the Annex. Table 5.17 summarizes energy use in the 1995 base year.

Table 5.17: Structure of commercial energy demand, 1995 (million GJ)

Subsector	End Use	Energy Use (GJ)
Government Services	Cooking	61.78
	Lighting	0.00
	Space Cooling	0.02
	Other Enduses	0.05
	Total	61.85
Non-Government Services	Cooking	13.42
	Space Cooling	0.00
	Lighting	0.00
	Other End-Uses	0.15
	Total	13.57
Construction	Machinery	3.07
Water Services	Purification & Pumping	0.31
Exploration	Drilling & Other	0.59
All Subsectors	Grand Total	79.39

As seen in Table 5.17, government services accounted for the greatest share of energy use (62 out of 79 million GJ, or about 78%), followed by non-government services (17%) and construction (4%). Energy use in the commercial sector is dominated by wood fuel (mostly urban firewood and some charcoal) as well as fuel oil. The commercial is a minor user of electricity, accounting for less than a 1% share of energy use in this sector. Most of the electricity is used for end uses such as space cooling and lighting in government and non-government buildings.

5.3.2.2 Key Assumptions Driving Future Developments

For the commercial sector, strong economic growth is assumed to occur foreseen is response to several regional and global economic initiatives that the government is pursuing (e.g., Red Sea Trade Zone), or government domestic policy initiatives (e.g., natural gas exploration and exploitation). Average economic growth rate assumptions are as follows:

- **Exploration:** 7.5%/year;
- **Construction:** 6.4%/year;
- **Government services:** 3.5%/yr (i.e., government policy encourages more commercial and services floor space);
- **Non-government services:** 4.2%/year;
- **Water services:** 7.2%/year.

5.3.2.3 Base Case GHG Emission Projections

Carbon dioxide emissions in the commercial sector between 1995 and 2025 are summarized in the Table 5.18 below. Overall, carbon dioxide emissions from the combustion of fossil fuels are small relative to emissions from the combustion of biomass resources, about 15%. Fossil-based emissions of carbon dioxide emissions increase from about 305 thousand tonnes in 1995 to 2,524 thousand tonnes in 2025, or about 7.3%/year. The use of fuel oil, which remains the dominant fossil fuel type throughout the planning period, increases substantially, by nearly 6-fold due primarily to the increasing activity in construction and exploration. The use of charcoal in the government and non-government subsectors (primarily for cooking end uses in shops, restaurants, and in government office buildings) is expected to increase by almost 4-fold. As in the household sector, the use of firewood declines significantly, but at a much more pronounced rate, -2.2%/year.

Table 5.18: Base Case carbon dioxide emissions from the Commercial sector

	Carbon dioxide Emissions (thousand tonnes)									
	Fossil fuels					Biomass Fuels				
	1995	2005	2015	2025	Growth	1995	2005	2015	2025	Growth
Subsector										
Government services	1	25	67	140	18.4%	5,980	8,220	11,280	15,490	3.2%
Non-gov.services	3	55	154	336	16.7%	1,290	1,480	1,560	1,370	0.2%
Construction	234	434	804	1,489	6.4%	0	0	0	0	-
Water services	23	46	92	183	7.2%	0	0	0	0	-
Exploration	44	89	183	376	7.4%	0	0	0	0	-
TOTAL	305	649	1,301	2,524	7.3%	7,269	9,697	12,843	16,858	2.8%
Fuel type										
Residual/Fuel Oil	214	396	734	1,359	6.4%	-	-	-	-	-
Diesel/Gas Oil	87	173	345	690	7.1%	-	-	-	-	-
LPG/Bottled Gas	4	79	222	476	17.1%	-	-	-	-	-
Firewood	-	-	-	-	-	2,508	2,617	2,330	1,269	-2.2%
Charcoal	-	-	-	-	-	4,761	7,080	10,513	15,589	4.0%
TOTAL	305	649	1,301	2,524	7.3%	7,269	9,697	12,843	16,858	2.8%
From Electricity	4	21	36	89	10.8%	-	-	-	-	-

5.3.2.4 Policies and Measures

The cost and performance of energy efficiency technologies in the commercial sector was obtained from international sources, as noted in the Annex. Targets were established using the Mitigation Team's judgment assuming an aggressive government to achieve GHG reductions. All measures were assumed to phase-in from a start year in 2005 to full penetration in 2025. Brief descriptions of each of the energy efficiency measures are provided below. Each of the subsections provides an overview of a) the technology itself, b) potential program approach, c) possible impediments to implementation in Sudan, d) a tabular summary of the cost and performance characteristics, including pertinent financial costing assumptions, and a summary of the penetration targets for the technology.

Efficient Lighting: Higher-than-standard efficiency lighting products 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. Reducing lighting energy use often has the important side-benefit of reducing air conditioning loads.

- **Target Consumer Groups:** Commercial, government, institutional, and religious-sector consumers, plus the street lighting sector; both new and existing buildings and installations.
- **Potential Program Approach/Implementation Strategy:** The goal of the program is to provide businesses and organizations (and those municipal entities that plan and implement street lighting) with incentives to choose and install more efficient lighting systems. 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 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". In an audit program, individuals (often engineers) trained in identifying and assessing demand side management opportunities visit a consumer's facilities, review the status and configuration of the energy consuming equipment on-site, analyze energy flow patterns in the building, and make suggestions as to what efficiency-improving modifications might be carried out. Audits of commercial and institutional facilities may be completed in a few hours, or may take several days. The audits may be 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 by government agencies in Sudan.
- **Possible Impediments to Implementation in Sudan:** As with many of the residential-sector programs, and as indicated above, 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.

- **Cost and Performance:** The costs and energy savings potential of this technology is the same as for the household application and has been summarized in the table in that subsection.
- **Targets:** In the year 2025, the use of CFLs in the government subsector 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 subsector, the use of CFLs increases from 0% to 50%. Details of the phase-in schedule for this technology are summarized in the Annex.

Efficient Air Conditioning: Higher-than-standard efficiency air conditioning and refrigeration equipment for commercial and institutional consumers, including higher-than-standard efficiency compressors, heat-exchangers, fans, control systems, and other associated equipment.

- **Target Consumer Groups:** Commercial, government, institutional, and religious-sector consumers; both new and existing buildings and installations.
- **Potential Program Approach/Implementation Strategy:** 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 and refrigeration 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.
- **Possible Impediments to Implementation in Sudan:** 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 a building. 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 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.
- **Cost and Performance:** The costs and energy savings potential of this technology is summarized in Table 5.19.
- **Targets:** In the year 2025, the use of high efficiency air conditioners in the government subsector increases from a 0% share of cooling technology stock in the options modeled affects electric consumption which is a relatively small component of overall energy use in the commercial sector.

Table 5.19: Efficient air conditioners

	Units			
Lifetime	Years	10		
Real Discount Rate	Percent	9%		
		Std Eff	Lower Cost	Higher Cost
Relative Efficiency		100%	82%	78%
Annual Energy Usage	kWh	1500	1230	1170
OM Cost	$	20	15	10
ADM Cost	$ per participant	0	0	0
Capital Cost	$	413	478	513
Annual Energy Savings	kWh	0	270	330
Inc. OM Cost	$	0	-5	-10
Inc. ADM Cost	$	0	0	0
Inc. Ann. Cap Cost	$	0	9.29	14.30
Cap Recovery Factor		0.143		
Cost of saved energy {	$/kWh	N/A	0.0159	0.0130
	$/GJ	N/A	4.4161	3.6160

5.3.3 Transport Sector

5.3.3.1 Current Energy Patterns

In 1995, passenger travel in Sudan was estimated to be about 14 billion passenger-kilometers traveled, with nearly 80% in the form of public transportation of various kinds (buses and small vans). Freight transport was estimated to be about 7 tonne-kilometers traveled with the overwhelming majority being on-road transport (about 97%).

Energy consumption in passenger and freight transport is estimated at about 28 million GJ. Major subsectors and energy end uses are depicted in the demand tree in Annex. Table 5.20 summarizes energy use in 1995. As seen in this table, passenger transport takes up the largest share of energy use (about 75%) with most of this used in public transit. Energy use in the transport sector is dominated by diesel fuel, which accounts for over 60% of total fuel consumption in transport. Gasoline and jet kerosene account for a 29% and 7% share, respectively.

Table 5.20: Structure of transport energy demand, 1995 (million GJ)

Subsector	End Use	Energy Use (GJ)
Passenger vehicles	*Private*	6.61
	Public	14.46
	total	21.07
Freight vehicles	*Road*	6.21
	Water	0.14
	Rail	0.06
	Air	0.3
	total	6.71
All Subsectors	***Grand Total***	27.78

5.3.3.2 Key Assumptions Driving Future Developments

For the transport sector, the following assumptions were made:

- Personal passenger travel keeps pace with population growth.
- The structure of government regulations, policies, customs and taxes stays in place.
- There is an expansion of the paved road network.
- Motor fuel prices increase over time (see assumptions in Table 5.8).
- Number and conditions of vehicles increases over time.
- There is a gradual increase in the efficiency of passenger and government vehicles over time in the Base Case (Cars, light trucks, and motorcycles: 0.5%/year; Buses: 0.25%/year; Heavy trucks, river boats, air travel, and rail: 0.125%/year).

5.3.3.3 Base Case GHG Emission Projections

Carbon dioxide emissions in the transport sector between 1995 and 2025 are summarized in Table 5.21. Total carbon dioxide emissions approximately double from about 2 million tonnes to 4 million tonnes, or about 2.5%/year. These emissions are dominated by diesel consumption for cars and buses, which more than doubles over the planning period, from 17 million GJ to 36 million GJ. By comparison, the share of gasoline for cars and jet kerosene for aircraft is small in 2025, roughly 31% and 8%, respectively, of total energy consumed in the transport sector.

Table 5.21: Base Case carbon dioxide emissions from the Transport sector

	Carbon dioxide Emissions (thousand tonnes)				
	1995	2005	2015	2025	Growth
Subsector					
passengers	1,506	2,054	2,625	2,977	2.3%
freight	489	683	917	1,162	2.9%
TOTAL	1,995	2,737	3,542	4,138	2.5%
Fuel type					
Residual/Fuel Oil	6	8	9	11	2.1%
Kerosene/Jet Fuel	149	213	287	346	2.9%
Gasoline	563	786	1,025	1,183	2.5%
Diesel/Gas Oil	1,278	1,730	2,220	2,598	2.4%
TOTAL	1,995	2,737	3,542	4,138	2.5%
From electricity	0	0	0	0	0

5.3.3.4 Policies and Measures

The cost and performance of energy efficiency technologies in the transport sector was obtained from international sources, as noted in the Annex. Targets were established using the Mitigation Team's judgment assuming an aggressive government to achieve GHG reductions. All measures were assumed to phase-in from a start year in 2005 to full penetration in 2025. Brief descriptions of each of the energy efficiency measures are provided below. Each of the subsections provides an overview of a) the technology itself, b) potential program approach, c) possible impediments to implementation in Sudan, d) a tabular summary of the cost and performance characteristics, including pertinent financial costing assumptions, and a summary of the penetration targets for the technology.

High Efficiency Vehicle Fleets: Higher-than-standard efficiency light duty and heavy duty vehicles, including buses, cars and light duty trucks.

- **Target Consumer Groups:** Government and commercial sector.
- **Potential Program Approach/Implementation Strategy:** The goals and possible program approaches for this are 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.
- **Possible Impediments to Implementation in Sudan:** The lack of coordination between Ministries of Energy and Transport and other counterparts represent a significant barrier to implement the above-mentioned policies and programs.
- **Cost and Performance:** The costs and energy savings potential of this technology is summarized in Table 5.22.
- **Targets:** 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. Details of the phase-in schedule for this technology are summarized in the Annex.

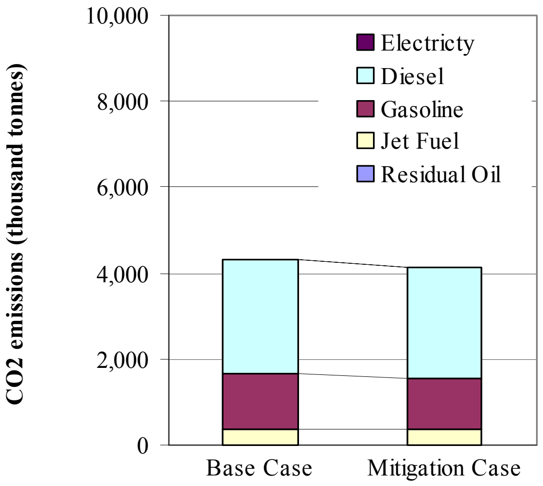
Table 5.22: High efficiency vehicle fleets

	Units	
Lifetime	Years	
Real Discount Rate	Percent	9%
Existing Vehicle Cost	$	15,000
lifetime	years	15
Cap Recovery Factor		0.114
Salvage value	$	1,500
Annualized cost	$	1,295
New Vehicle Cost	$	30,000
lifetime	years	10
Cap Recovery Factor		0.143
Salvage value	$	6,525
Annualized cost	$	1,532
Avg fuel economy of existing fleet vehicles	mpg	14
Avg fuel economy of new fleet vehicles	mpg	29
Avg VMT	km/year	14,250
Annual Energy Savings	GJ	40.60
Inc. OM Cost	$	0
Inc. ADM Cost	$	0
Inc. Ann. Cap Cost	$	237.0
Cost of saved energy	$/GJ	5.837

5.3.3.5 Mitigation Analysis Results

Carbon dioxide emissions in the transport sector in 2025 are summarized in Figure 5.5 for the Base and Mitigation cases. As is the case with the commercial sector, reductions in the transport sector are small on a percentage basis, only 4% lower in 2025 than the Base Case level. This is due to the fact that public vehicle fleets are a small component of total end use in the transport sector.

Figure 5.5: CO2 reductions by fuel in the Transport Sector, 2025



	Base Case	Mitigation Case
Electricty	0	0
Diesel	2,634	2,598
Gasoline	1,312	1,183
Jet Fuel	346	346
Residual Oil	11	11

5.3.4 Industrial Sector

5.3.4.1 Current Energy Patterns

In 1995, energy consumption in the industrial sector totaled about 35 million GJ. Major subsectors and energy end uses are depicted in the demand tree in Annex. Table 5.23 summarizes energy use in 1995. As seen in this table, industrial energy use is distributed rather evenly across the sugar, food/oil, and cement subsectors which 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. Process heat in other industries is produced using fuel oil. Motive power is also used extensively in each of the industrial subsectors, with the greatest share corresponding to processes involved in the production of cement.

Table 5.23: Structure of industrial energy demand, 1995 (million GJ)

Subsector	End Use	Energy Use (GJ)
Sugar	Process Heat	6.49
	Motive Power	0.11
	Total	6.6
Food& Edible Oil	Process Heat	10.16
	Motive Power	0.75
	Total	10.91
Textile	Process Heat	2.95
	Motive Power	0.04
	Total	2.99
Cement	Process Heat	7.26
	Motive Power	0.13
	Total	7.39
Other Industries	Process Heat	0.1
	Motive Power	0.66
	Total	0.76
Other Enduse	All Uses	6.25
All Subsectors	Grand Total	34.89

5.3.4.2 Key Assumptions Driving Future Developments

For the industrial sector, several assumptions govern the types of fuels consumed and their magnitude:

- There is a gradual penetration of new, more efficient process heat technology in the sugar and food/edible oils industries.
- Government policy encourages expansion in certain subsectors (Sugar: 6.5%/yr; Food & edible oils: 11.4%/yr).
- Productivity of other subsectors (textiles, cement, and other heavy industries) remains at 1995 levels.

5.3.4.3 Base Case GHG Emission Projections

Carbon dioxide emissions in the industrial sector between 1995 and 2025 are summarized in Table 5.24. The growth carbon dioxide emissions in this sector is in sharp contrast to that of other sectors in the Sudan economy. Overall emissions from fossil fuels increase from about 1.4 million tonnes to 15.4 million tonnes, and mirrors planned industrial development for certain subsectors (primarily food subsectors). Biogenic carbon dioxide emissions are initially a relatively large share of total emissions (54%) by comparison but decrease to a level in 2025 that is just under 4% of total emissions, including electricity. The increase in energy use is dominated by electricity for use in motors which increases by 15-fold over the period (from 2 million GJ to 21 million GJ). Notably, the use of bagasse in sugar factories decreases significantly over time.

5.3.4.4 Policies and Measures

The cost and performance of energy efficiency technologies in the industrial sector was obtained from international sources, as noted in the Annex. Targets were established using the Mitigation Team's judgment assuming an aggressive government to achieve GHG reductions. All measures were assumed to phase-in from a start year in 2005 to full penetration in 2025. Brief descriptions of each of the energy efficiency measures are provided below. Each of the subsections provides an overview of a) the technology itself, b) potential program approach, c) possible impediments to implementation in Sudan, d) a tabular summary of the cost and performance characteristics, including pertinent financial costing assumptions, and a summary of the penetration targets for the technology.

Table 5.24: Base Case carbon dioxide emissions from the Industrial sector

	Carbon dioxide Emissions (thousand tonnes)									
	Fossil fuels					Biomass Fuels				
	1995	2005	2015	2025	Growth	1995	2005	2015	2025	Growth
Subsector										
Sugar	60	800	2,720	7,320	17.4%	1,039	1,368	1,477	723	-1.2%
food& edible oil	90	450	1,830	6,820	15.5%	875	1,717	2,526	0	-100.0%
Textile	230	230	230	230	0.0%	-	-	-	-	-
Cement	550	550	550	550	0.0%	-	-	-	-	-
other industries	0	0	0	0	-	-	-	-	-	-
other enduse	460	460	460	460	0.0%	-	-	-	-	-
TOTAL	1,394	2,480	5,783	15,373	8.3%	1,913	3,085	4,003	723	-3.2%
					-					
Fuel type					-					
Residual/Fuel Oil	936	2,023	5,325	14,915	9.7%	-	-	-	-	-
Diesel/Gas Oil	457	457	457	457	0.0%	-	-	-	-	-
Firewood	0	0	0	0	-	824	1,618	2,381	0	-100.0%
Bagasse	0	0	0	0	-	1,089	1,467	1,622	723	-1.4%
TOTAL	1,394	2,480	5,783	15,373	8.3%	1,913	3,085	4,003	723	-3.2%
From Electricity	248	802	1,333	3,993	9.7%	-	-	-	-	-

Efficient Electric Motors: 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 applications. With their typically high capacity factor (running time per year), industrial motors are usually prime candidates for highly cost-effective efficiency improvements.

- **Target Consumer Groups:** Industrial facilities, including private, semi-private, and ministry-owned factories.
- **Potential Program Approach/Implementation Strategy:** 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 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.

- **Possible Impediments to Implementation in Sudan:** 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.
- **Cost and Performance:** The costs and energy savings potential of this technology is summarized in Table 5.25.

Table 5.25: High efficiency electric motors

	Units	
Lifetime	Years	15
Real Discount Rate	Percent	9%
Incremental Cost	$	$97
Annual Energy Savings	kWh	400
Inc. OM Cost	$	0
Inc. ADM Cost	$	0
Inc. Ann. Cap Cost	$	11.04
Cap Recovery Factor		0.114
Cost of saved energy	$/kWh	0.03
	$/GJ	7.67

- **Targets:** 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 subsectors. Details of the phase-in schedule for this technology are summarized in the Annex.

High Efficiency Boilers: Higher-than-standard efficiency boilers for use in variety of medium to large industries. Boilers are usually prime candidates for highly cost-effective efficiency improvements.

- **Target Consumer Groups:** Sugar factories, edible oil, refineries, sweets, soap, textile, corrugated board, and bakeries are the important target consumer groups.
- **Potential Program Approach/Implementation Strategy:** 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.
- **Possible Impediments to Implementation in Sudan:** 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.
- **Cost and Performance:** The costs and energy savings potential of this technology is summarized in Table 5.26.

Table 5.26: High efficiency boilers

	Units	
Lifetime	Years	30
Real Discount Rate	Percent	9%
Incremental Cost	$	
Annual Energy Savings	GJ/tonne steam	1000
Inc. OM Cost	$	0
Inc. ADM Cost	$	0
Inc. Ann. Cap Cost	$	35,000
Cap Recovery Factor		0.089
Cost of saved energy	$/GJ	8.93

- **Targets:** 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.

5.3.4.5 Mitigation Analysis Results

Carbon dioxide emissions in the industrial sector for 2025 are summarized in Figure 5.6 for the Base and Mitigation cases. Relative to the Base Case in 2025, the mitigation options reduce emissions of carbon dioxide from nearly 20 million tonnes to about 17 million tonnes, or by about 14%. The largest reduction is associated with electricity-related emissions, which are reduced by almost 30%.

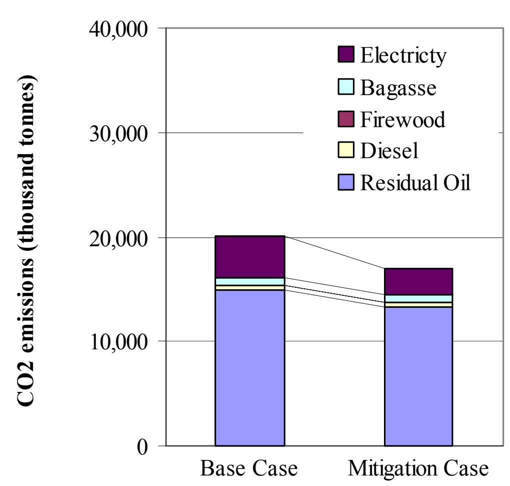
5.3.5 Agricultural Sector

5.3.5.1 Current Energy Patterns

In 1995, energy consumption in the agricultural sector totaled about 8 million GJ. Major subsectors and energy end uses are depicted in the demand tree in Annex. Table 5.27 summarizes energy use in 1995.

As seen in table 5.27, agricultural energy use is dominated by the use of pumps (diesel-, fuel oil-, and electric-operated) in irrigated farmlands, accounting for 5 million GJ, or over 60% of total energy consumed in this sector. Energy use for other operations in the agricultural sector, using diesel-operated machines, accounts for the balance of 3 million GJ, or slightly less than 40% of total sectoral energy use.

Figure 5.6: CO2 reductions by fuel in the Industrial Sector, 2025



	Base Case	Mitigation Case
Electricty	3,993	2,532
Bagasse	723	723
Firewood	0	0
Diesel	457	457
Residual Oil	14,915	13,310

Table 5.27: Structure of agricultural energy demand, 1995 (million GJ)

Subsector	End Use	Energy Use (GJ)
Mechanized Rain-Fed	Operations	1.78
Irrigated	Operation	1.17
	Pumping	4.96
	Total	6.13
All Subsectors	Grand Total	7.92

5.3.5.2 Key Assumptions Driving Future Developments

For the agricultural sector, several assumptions were made as summarized below:

- Pumping on irrigated lands increases from 40% in 1995 to 70% by 2025.
- By 2025, only diesel and high efficiency electric pumps will be used with a share of 90% and 10%, respectively.
- In mechanized rain-fed farms, only diesel-fueled machines are projected to be used during the forecasted period.
- No fuel is used in traditional rain-fed agriculture.

5.3.5.3 Base Case GHG Emission Projections

Carbon dioxide emissions in the agricultural sector between 1995 and 2025 are summarized in the Table 5.28. Overall carbon dioxide emissions increases from about 0.6 million tonnes to 5.3 million tonnes, representing a 9-fold increase in 30 years, or about 6.4%/year. The increase in energy use is dominated by diesel use for irrigation pumping and to the greater use of electric pumps for irrigation.

Table 5.28: Base Case carbon dioxide emissions from the Agriculture sector

	Carbon dioxide Emissions (thousand tonnes)				
	1995	2005	2015	2025	Growth
Subsector					
mechanized rainfed	131	306	492	687	5.7%
irrigated	405	960	1,497	1,954	5.4%
TOTAL	536	1,266	1,988	2,641	5.5%
Fuel type					
Residual Oil	0.01	0.02	0.02	0.00	-100.0%
Diesel/Gas Oil	536	1,266	1,988	2,641	5.5%
TOTAL	536	1,266	1,988	2,641	5.5%
From electricity	84	776	1,388	2,855	12.5%

5.3.5.4 Policies and Measures

As indicated earlier, no mitigation options were modeled for the agricultural sector.

5.4 Energy Supply Analysis

5.4.1 Current Situation

Table 5.29 shows electricity production over the 1990-95 period. Throughout this period, the household sector has been the major consumer of electricity. Technical and administrative losses have been escalating during this period and power cuts have been quite common. Due to the fact that these final figures became available rather late in the mitigation analysis, they are slightly different than base year electricity use that was modeled within LEAP. However, differences between actual electricity consumption or production and levels assumed in the analysis were small, generally less than 10%.

Table 5.29: Actual electricity generation and consumption 1990-1995 (GWh)

Sector	1990	1991	1992	1993	1994	1995
Household	872	683	701	524	671	780
Commercial	36	70	52	34	55	74
Industrial	351	377	349	388	416	378
Agriculture	27	35	40	27	35	33
Governmental services	111	88	105	37	73	78
Total sales	1,397	1,253	1,247	1,010	1,250	1,343
Losses	4%	20%	19%	38%	33%	28%
Total Generated	**1,451**	**1,575**	**1,535**	**1,633**	**1,858**	**1,864**

The characteristics of the existing electric supply system—such as plant capacity, efficiency, and location—were readily available and were easily integrated into the analysis. Other types of information, particularly information on plant operating costs, were more difficult to obtain and required an initial effort to gather, summarize, and assign representative values. Plant types and capacities are summarized in the Table 5.30. Installed electric generating capacity consists of a combination of hydro, steam, diesel and gas turbines.

Table 5.30: Base Case electric supply summary

	1995	2005	2015	2025
Capacity (MW)				
Hydro	308	308	1,715	1,715
Oil Steam	165	1,065	1,765	3,765
Conventional Gas Turbine	66	416	1,066	1,866
Diesel	188	272	272	272
Wind	0	0	0	0
Solar	0	0	0	0
Conventional Combined Cycle	0	0	900	1,500
Total	727	2,061	5,718	9,118
Generation (GWh)				
Hydro	970	810	3,720	4,700
Oil Steam	630	3,090	4,100	11,480
Conventional Gas Turbine	70	1,110	2,320	5,130
Diesel	190	430	370	440
Wind	0	0	0	0
Solar	0	0	0	0
Conventional Combined Cycle	0	0	2,090	4,570
Total	1,860	5,440	12,600	26,320
Fossil fuel use (million GJ)				
Natural gas	0.0	0.0	16.9	34.2
Diesel	3.7	21.0	33.9	65.9
Residual oil	6.2	29.8	40.2	110.9
Total	9.8	50.8	90.9	211.0

5.4.2 Key Assumptions Driving Future Developments

The production of existing oil fields and refineries of large quantities of fuel oil and diesel is a significant factor in securing fuel for power generation. 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 later on the study period, around 2010 and later. The availability of natural gas for use in electric generation is assumed.

Electric expansion is driven by assumptions in electric demand. In the past, most electricity demand forecasting efforts in Sudan have been of a short-term (and for certain studies on a long-term basis) nature, based primarily on trending analyses. The most detailed and recent electricity demand forecast has been done for the Development Plan 1998-2003, and folds in the demand side consumption drivers outlined in previous sections. Committed and planned generation and transmission additions to the national electric grid have been input to the expansion plans in both the Base and Mitigation Cases, based on information from NEC.

Cost and performance of new fossil and renewable supply options for electric system expansion, including fuel requirements and maintenance schedules were based on current international values, or local values where good information existed based on recent assessments done for the Government of Sudan. Gradual improvement in the heat rates of certain conventional fossil capacity (i.e., combined cycle and combustion turbines) was assumed in the analysis. See the Annex for a summary of new fossil technology cost and performance inputs.

5.4.3 Base Case Projections

Official NEC estimates show that the demand for electric power (MW) and energy (GWh) is expected to grow steeply during the next ten years. In representing electric sector expansion within LEAP, the short-term capacity expansion plan developed by the NEC was used. Beyond the year 2010, for which no official plan exists, the mitigation team relied on the expert judgment of specialists within the electric industry in Sudan. Future unplanned capacity investments to meet load growth are thermal facilities as remaining hydro resources that could be exploited are too costly in comparison. New capacity consists of oil steam units, natural gas combined cycle (conventional technology), and gas turbines (conventional technology).

Electric capacity and generation (by plant type), as well as fuel requirements between 1995 and 2025 are summarized in Table 5-29. System capacity increases from about 727 MW in 1995 to 9,118 MW in 2025, or about 8.8%/year. Generation increases from about 2 TWh to 26 TWh, representing an over 13-fold increase in 30 years, or about 9.2%/year. The share of hydro generation drops from over half to just under 20% of total generation. The efficiency of fossil generation improves from about 35% in 1995 to 39% in 2025, due to the declining share of small isolated diesel generators and the addition of efficient combined cycle units.

5.4.4 Policies and Measures

As indicated earlier, renewable energy and high efficiency fossil units are the focus of mitigation opportunities. For the fossil units, advanced combined cycle and combustion turbine units were used that had higher conversion efficiency (and higher costs) than conventional alternatives.

For renewable energy, alternatives were characterized with respect to the available resource potential in the country. 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 because there is a general lack of information for those applications in which renewables can make economic sense. Analysts are typically unaware of technologies and practices that can conserve fossil energy, limiting the degree to which utility engineers to make use of operational developments in integrating intermittent renewable technology in the national electric supply system. All these factors contribute toward the perception that renewable resources are significantly more financially risky than conventional resources, particularly in the context of the relatively short planning horizons typically used in Sudan.

Since traditional utility planning in Sudan has favored large, dispatchable power sources over decentralized, intermittent options, there exists a lack of familiarity and experience with alternative energy technologies on the part of utility managers and engineers. Using 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 Sudanese renewable resource potential described earlier, solar thermal hybrid systems (that is, with natural gas backup) and wind turbines were considered most suitable in this initial mitigation assessment. For wind, the mitigation team chose a target of 400 MW in 2025. For solar thermal, a total of 300 MW is added with the first units brought on line in 2015.

5.4.5 Mitigation Analysis Results

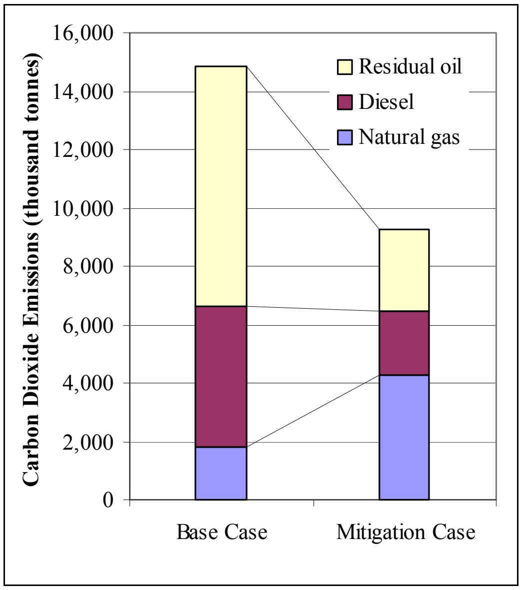
Table 5.31 compares capacity, generation, and fuel consumption in the Sudan electric sector in 2025 for the Base and Mitigation Cases. After all supply and demand side measures, renewables represent about 30% of total capacity and about 23% of total generation. For base load fossil generation, the shift away from oil steam to an increased use of natural gas in combined cycle units results in over twice the level of natural gas inputs in 2025. Fossil system efficiency improves from 39% in the Base Case to 46% in the Mitigation Case, owing primarily to the large share of advanced combined cycle units.

Carbon dioxide emissions in the electric supply sector between 1995 and 2025 are summarized in Figure 5.7. Relative to the Base Case in 2025, the mitigation options reduce emissions of carbon dioxide by 5.6 million tonnes, from 14.8 million tonnes to about 9.2 million tonnes, or about 38%. The largest reduction is associated with electricity-related emissions which are reduced by almost 30%.

Table 5.31: Electric capacity, generation, and fuel use, Base & Mitigation Cases in 2025

	Base	Mitigation	Reduction
Capacity (MW)			
Hydro	1,715	1,715	0
Oil Steam	3,765	765	3,000
Gas Turbine	1,866	1,766	100
Diesel	272	272	0
Wind	0	400	-400
Solar	0	300	-300
Combined Cycle	1,500	2,900	-1,400
Total	9,118	8,118	1,000
Generation (GWh)			
Hydro	4,700	5,130	-430
Oil Steam	11,480	3,260	8,220
Gas Turbine	5,130	1,930	3,200
Diesel	440	490	-50
Wind	0	110	-110
Solar	0	80	-80
Combined Cycle	4,570	12,350	-7,780
Total	26,320	23,350	2,970
Fossil fuel use (million GJ)			
Natural gas	34	83	-48
Diesel	66	30	36
Residual oil	111	38	73
Total	211	151	60

Figure 5.7: CO2 Emissions by fuel in the Electric Supply Sector, 2025



5.5 Synthesis and Recommendations

If implemented, the combined effect of the mitigation measures discussed in the previous sections will substantially reduce overall emissions of carbon dioxide in Sudan. Taking the mitigation options across all sectors into account results in reduced carbon dioxide emissions of 7 million tonnes (fossil-based), a 17% reduction by 2025, and about 12 million tonnes (biomass-based), a 25% reduction by 2025. Total carbon dioxide emissions and reductions by sector are summarized in Figures 5.8 through 5.10 (see the Annex for a detailed tabular breakdown of GHG emissions in the Mitigation Case).

Figure 5.8: Total Projected Carbon Dioxide Emissions, Base and Mitigation Cases, biomass and fossil-based emissions

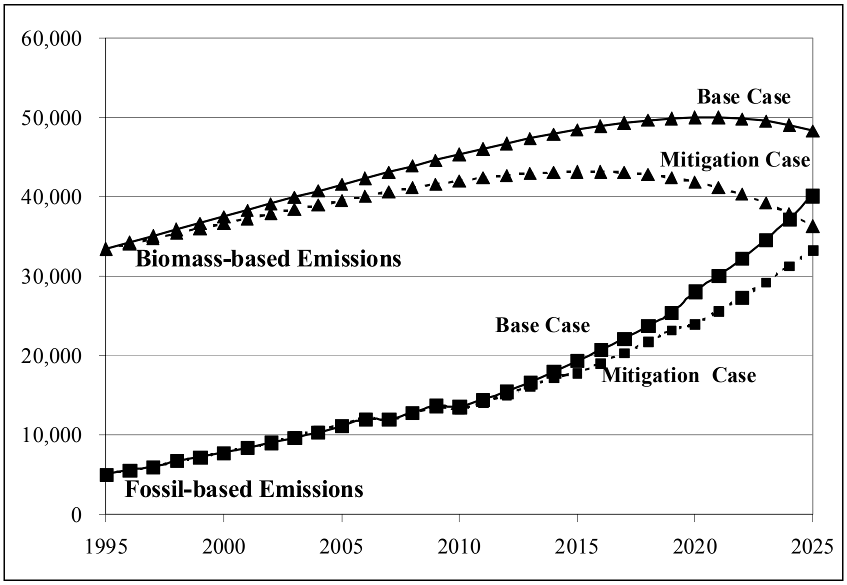


Figure 5.9: Carbon dioxide emission reductions by sector, biomass-based

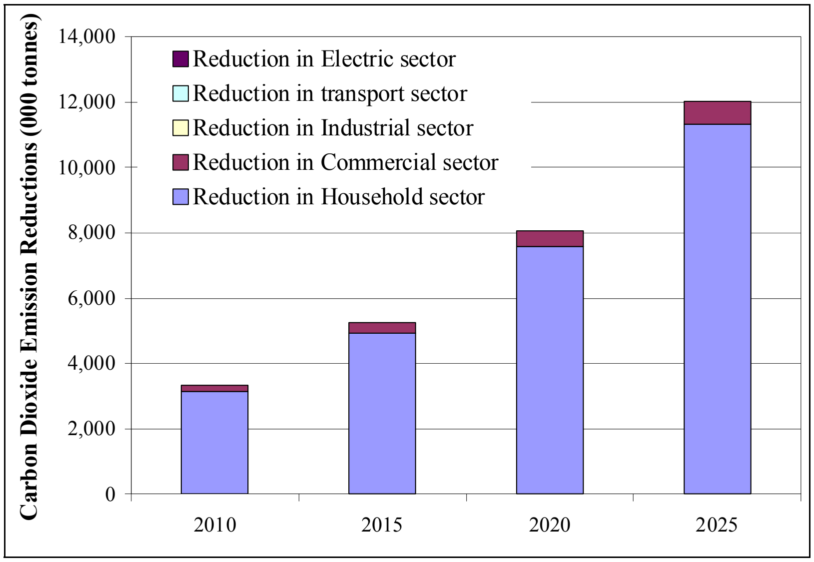
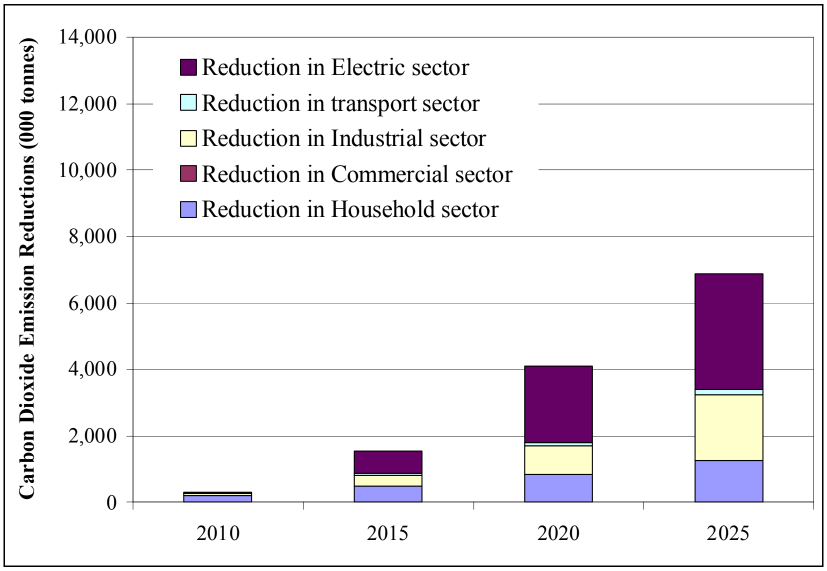


Figure 5.10: Carbon dioxide emission reductions by sector, fossil-based



5.5.1 Cost Impacts of Mitigation Options

Table 5.32 summarizes the incremental costs of all measures analyzed in the Mitigation Case (i.e., both on the supply and on the demand side). The costs in this table represent the cumulative effect on the discounted non-fuel and fuel costs of all mitigation measures, on both the demand and supply side, of efficiency and renewable energy options. As can be seen, 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 development priorities.

5.5.2 Major Challenges and Follow-up

Preparation of this mitigation assessment for Sudan has helped to point out areas where additional data collection and assembly will be necessary to inform 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 in the subsections below.

Table 5.32: Cost of demand and supply side options (million discounted US$, at 5%)

	Benefits	Costs	NPV	B/C Ratio
Demand Non-Fuel Costs				
Household	0.1	29.0	-28.9	
Commercial	0.0	4.1	-4.1	
Transportation	0.0	41.9	-41.94	
Industry	4.3	129.9	-125.6	
Agriculture	0.0	0.0	0.0	
Electric Non-Fuel Costs				
Distribution	0.0	0.0	0.0	
Electricity Gen.	1173.9	574.5	599.4	
Oil Refining	0.0	0.0	0.0	
Charcoal Production	0.0	0.0	0.0	
Gas Production	0.0	0.0	0.0	
Crude Oil Production.	0.0	0.0	0.0	
Resource Costs				
Indigenous	4.4	79.6	-75.2	
Imports	1170.0	667.0	503	
Exports	0.0	0.0	0.0	
Total Energy System	2352.7	1526.0	826.7	1.54

5.5.2.1 Capacity Strengthening on the Energy Demand Side

In the process of conducting the GHG mitigation analysis of demand side options in Sudan, it became clear to the mitigation team that several follow-up activities, which if carried out, would provide a valuable basis for conducting the next analysis.

Data collection and lack of availability of data: The General Directorate for the National Energy Affairs is currently responsible for routine collection of a wide range of detailed energy statistics at the national level. Recently (in late 1998) the second Sudan Energy Assessment project was undertaken and, at the time of this writing, was at the stage of data analysis and writing the final reports (the first assessment was conducted in 1981) and was therefore unavailable to the mitigation team. However, such a process will be important to future updating efforts.

A major area where data were found to be lacking was end-use data on the consumption of fuels and electricity in homes, businesses, industries, and other buildings in the base year 1995. These data are needed for detailed mitigation assessment, as well as for end-use forecasting. Further efforts in Sudan would be aided greatly by supporting the ongoing program of end-use data collection (Second National Energy Assessment Project) designed to be consistent with collection of data on consumption of electricity and other fuels.

Comparability of data across ministerial sources: Different ministries in Sudan collect energy consumption and activity (for example, value added) data in different ways. Different definitions of sub-sectors used for categorizing electricity and economic data, for example, make the process of forecasting more challenging. Similarly, the categorization of consumers used in the collection of data on non-transport oil products consumption is not typically the same as that used for collection of electricity consumption data.

To the extent that electricity and fossil fuels are sometimes substitutes, consistency in the keeping of consumption data on both fuels will be helpful in future mitigation assessment efforts. Economic data also, in some cases, lack comparability across ministries. Overall, enhanced coordination between ministries will be helpful in creating a body of background data that is directly useful for subsequent rounds of mitigation analysis.

Ongoing capacity building in GHG mitigation analysis: The current UNDP enabling activities project in Sudan has provided an excellent basis upon which to continue to build institutional capacity for planning related to climate change. At this point, however, the existing climate change office staff would be hard pressed to research and prepare a full-fledged mitigation analysis for Sudan, due to lack of detailed training in specific areas and to the small size of the mitigation assessment group. Additional efforts on behalf of the HCENR, partner agencies in Sudan, and outside institutions providing assistance in climate change fields are required to continue deepening and broadening the capabilities for GHG mitigation analysis functions. New and ongoing initiatives in these areas should include adding staff, providing specialized training in specific areas of mitigation assessment, and developing the types of connections between agencies in Sudan that will facilitate the planning process.

Integration of mitigation options into national planning: As many of the elements of a mitigation assessment in Sudan cross traditional ministerial boundaries, it is not clear 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. If all participants understand the institutional responsibility for follow-up before the mitigation assessment process begins, it would make the process smoother and more efficient.

Need for end-use data collection: 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.

Need for collection of information on appliance, equipment efficiencies: There is at present no systematic compilation of appliance and equipment types, models, efficiencies, costs, and other technical parameters in Sudan. Such an information base will be needed in the future for use in preparing a more accurate and detailed end-use electricity forecast, as well as in assessing and implementing GHG reduction measures and programs. Especially to the extent that some appliances are manufactured in-country and are thus not covered by the (relatively few) international information compendia that do exist, Sudan-specific information will be needed.

Compilation of a database of appliance and equipment information should be a relatively straightforward process, but will require significant staffing. Information should be gathered both on the new equipment being manufactured in Sudan and imported to Sudan (as well as imports of used equipment, to the extent that such imports are important), and on existing equipment in use in homes, businesses, and other locations. There will be a need for researchers who will go to appliance and equipment dealers and manufacturers and compile the necessary data on new appliances and equipment, as well as survey personnel and technical auditors to assess the types, status, and efficiencies of appliances and equipment currently in use. The latter effort, of course, could be integrated as a part of the end-use surveys suggested above.

Training in demand side management-related disciplines: Throughout the descriptions of 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 early years as the HCENR builds up its GHG mitigation assessment capabilities.

5.5.2.2 Capacity Strengthening on the Energy Supply Side

In the process of conducting the mitigation analysis of supply options in Sudan, it became clear to the mitigation team that several follow-up activities, which if carried out, would provide a valuable basis for conducting the next analysis.

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.

Data Collection Power Plant Cost and Performance in a Form Suitable for Modeling: At the present time, data on plant costs (for example, fuel, O&M, land, etc) is compiled in a way that requires substantial reformatting for use in a model such as LEAP. Systematizing this sort of information with a view to using it in future mitigation studies would not only serve to streamline the process but also provide a valuable cross-checking function.

Development and Systematic updating of a Supply Technology Database: Results from international research and development efforts and prototype installations for advanced fossil technologies and renewable technologies indicate that significant cost and performance enhancements are occurring over time. To keep abreast of these developments, the HCENR would be well served to establish a technology database development unit to obtain data from published international sources. Alternatively, the HCENR could avail itself of any of a number of suitable databases developed and regularly updated by international organizations.

5.6 Annex

The information presented in this Appendix is based on LEAP data set SUDAN-F3, dated January 2001. The following information is presented:

1) *Energy demand tree*
2) *Energy demand summary, Base Case*
    a) Energy Demand, by Fuel by Year, All Sectors
    b) Energy Demand, by Sector by Year, All Fuels
    c) Energy Demand, Household Sector by End-use, by Year, All Fuels
    d) Energy Demand, Household Sector by Fuel, by Year, All End-uses
    e) Energy Demand, Commercial Sector by End-use, by Year, All Fuels
    f) Energy Demand, Commercial Sector by Fuel, by Year, All End-uses
    g) Energy Demand, Transport Sector by End-use, by Year, All Fuels
    h) Energy Demand, Transport Sector by Fuel, by Year, All End-uses
    i) Energy Demand, Industrial Sector by End-use, by Year, All Fuels
    j) Energy Demand, Industrial Sector by Fuel, by Year, All End-uses
    k) Energy Demand, Agricultural Sector by End-use, by Year, All Fuels
    l) Energy Demand, Agricultural Sector by Fuel, by Year, All End-uses
3) *Mitigation Energy Savings Targets*
    a) High efficiency Air Conditioners
    b) Compact Fluorescent Lighting
    c) Evaporative Coolers
    d) LPG cookers
    e) Solar Cookers
    f) High Efficiency Vehicle Fleets
    g) High Efficiency Electric Motors
4) *Energy demand summary, Mitigation Case*
    a) Energy Demand, by Fuel by Year, All Sectors
    b) Energy Demand, by Sector by Year, All Fuels
    c) Energy Demand, Household Sector by End-use, by Year, All Fuels
    d) Energy Demand, Household Sector by Fuel, by Year, All End-uses
    e) Energy Demand, Commercial Sector by End-use, by Year, All Fuels

   - *f)* Energy Demand, Commercial Sector by Fuel, by Year, All End-uses
   - *g)* Energy Demand, Transport Sector by End-use, by Year, All Fuels
   - *h)* Energy Demand, Transport Sector by Fuel, by Year, All End-uses
   - *i)* Energy Demand, Industrial Sector by End-use, by Year, All Fuels
   - *j)* Energy Demand, Industrial Sector by Fuel, by Year, All End-uses
   - *k)* Energy Demand, Agricultural Sector by End-use, by Year, All Fuels
   - *l)* Energy Demand, Agricultural Sector by Fuel, by Year, All End-uses

5) Cost and Performance Characteristics of New Electric Supply Technologies

6) Base Case Electric Supply Plan

   - *a)* Generation (TWh)
   - *b)* Capacity (MW)
   - *c)* Fuel Use (million GJ)

7) Mitigation Case Electric Supply Plan

   - *a)* Generation (TWh)
   - *b)* Capacity (MW)
   - *c)* Fuel Use (million GJ)

8) Base Case Carbon Dioxide Emissions (million tonnes)

9) Mitigation Case Carbon Dioxide Emissions (million tonnes)

10) Energy Use Summary Charts – Base Case

11) Energy Use Summary Chart – Mitigation Case

1) Energy Demand Tree for Sudan

The schematic diagram below summarizes the assumed flows of energy throughout the Sudanese economy. This is the energy demand structure that was developed within the LEAP modeling framework.

```
┌─Household────┬─URBAN-ELECTR─┬─OTHER-ENDUSE───BACK-UP ELEC
│              │              ├─LIGHTING─────┬─KEROSENE LAM
│              │              │              └─ELEC LAMPS
│              │              ├─REFRIGERATIO───ELECTRIC-REF
│              │              ├─COOKING──────┬─ELEC STOVE
│              │              │              ├─LPG STOVE
│              │              │              ├─CHARCOAL STO
│              │              │              └─WOOD STOVE
│              │              └─AIR COOLING──┬─air conditio
│              │                             └─air coolers
│              ├─Urban-NONELE─┬─cooking──────┬─charcoal sto
│              │              │              ├─LPG stove
│              │              │              └─wood stove
│              │              └─lighting───────kerosene lan
│              ├─RURAL-ELECTR─┬─OTHER-ENDUSE───ELECTRIC-APP
│              │              ├─REFRIGERATIO───ELCTRIC-REFR
│              │              ├─LIGHTING─────┬─KEROSENE LAM
│              │              │              └─ELEC LAMPS
│              │              └─COOKING──────┬─LPG
│              │                             ├─WOOD
│              │                             ├─CHARCOAL
│              │                             └─SOLAR COOKER
│              └─RURAL-NONELE─┬─cooking──────┬─charcoal sto
│                             │              ├─Wood stove
│                             │              ├─LPG stove
│                             │              └─SOLAR COOKER
│                             └─lighting───────kerosine
├─commercial───┬─governemnt s─┬─cooking──────┬─lpg
│              │              │              ├─charcoal
│              │              │              └─wood
│              │              ├─lighting───────electric dev
│              │              ├─SPACE COOLIN───A/C
│              │              └─other enduse─┬─electricity
│              │                             ├─CHARCOAL
│              │                             ├─WOOD
│              │                             └─LPG
│              ├─non-gov.serv─┬─cooking──────┬─wood
│              │              │              ├─lpg
│              │              │              └─charcoal
│              │              ├─SPACE COOLIN───A/C
│              │              ├─Lighting───────electricity
│              │              │
```

```
│              │              └─other end-us─┬─LPG
│              │                             ├─electricity
│              │                             ├─CHARCOAL
│              │                             └─wood
│              ├─construction───MACHINERY────┬─diesil
│              │                             └─fueloil
│              ├─WATER SERVIC───Pur.&Pumping───Diesel
│              └─exploration────DRILLING & O───Diesil
├─transportati─┬─passengers───┬─private───────┬─motorcycle
│              │              │               ├─Diesel Cars
│              │              │               └─Petrol Cars
│              │              └─public────────┬─buses diesel
│              │                              ├─buses gasoli
│              │                              ├─rail diesel
│              │                              ├─rail fuel oi
│              │                              ├─taxis gasoline
│              │                              ├─taxis diesel
│              │                              ├─gov.diesel c
│              │                              ├─gov.gasoline
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│              │                              ├─river diesel
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│              │                              └─Airoplane av
│              └─freight──────┬─road──────────┬─small diesil
│                             │               ├─small gazoli
│                             │               └─large diesil
│                             ├─water─────────┬─ships fuel o
│                             │               └─ships diesil
│                             ├─rail──────────┬─diesel
│                             │               └─fueloil
│                             └─air───────────┬─avogas
│                                             └─jet
├─industry─────┬─sugar────────┬─process heat─┬─bagass fired
│              │              │              └─furnace boil
│              │              └─motive power───electric mot
│              ├─food& edible─┬─process heat─┬─furnace boil
│              │              │              ├─wood fired b
│              │              │              └─bagasse fire
│              │              └─motive power───electric mot
│              ├─textile──────┬─process heat───furnace boil
│              │              └─motive power───electric mot
│              ├─cement───────┬─process heat─┬─furnace boil
│              │              │              └─electric hea
│              │              └─motive power───electric mot
│              ├─other indust─┬─process heat─┬─furnace boil
│              │              │              └─electricity
│              │              │
```

```
│              │              └─motive power───electric mot
│              └─other enduse───all uses─────┬─electricity
│                                            └─diesil
└─agriculture──┬─mechanized r───operation──────Diesel Machi
               └─irrigated────┬─operation──────diesil Machi
                              └─pumping──────┬─CONV EFF PUM
                                             ├─diesil
                                             ├─fuel oil
                                             └─HIGH EFF PUM
```

2) *Energy Demand Summary, Base Case*

The following tables summarize the consumption of energy in the Base Case over the 1995-2025 period, in increments of 5 years. A total of 12 tables are provided, 2 for each of the five demand sectors, and 2 describing energy demand across all sectors.

a) Energy Demand, by Fuel by Year, All Sectors

	1995	2000	2005	2010	2015	2020	2025
ELECTRICITY	5.37	9.51	15.63	24.3	36.33	52.89	75.84
GASOLINE	8.2	9.83	11.65	13.61	15.64	17.56	19.1
KEROSENE/JETFUEL	2.35	2.91	3.54	4.23	4.95	5.63	6.2
DIESEL/GAS OIL	32.85	41.45	50.53	59.94	69.44	78.76	87.48
RESIDUAL/FUELOIL	15.09	21.19	31.67	49.42	79.2	129.04	212.53
LPG/BOTTLED GAS	0.86	1.85	3.13	4.77	6.86	9.5	12.84
FIREWOOD	168.32	173.3	177.09	178.5	174.82	160.24	122.51
CHARCOAL	132.26	167.67	204.78	242.66	279.97	314.93	345.13
BAGASSE	24.81	24.33	23.58	22.53	21.14	19.42	17.36
URBAN FUELWOOD	5.92	6.98	7.98	8.72	8.82	7.61	3.93
TOTAL	403.48	466.41	536.8	615.56	703.57	801.3	907.71

b) Energy Demand, by Sector by Year, All Fuels

	1995	2000	2005	2010	2015	2020	2025
HOUSEHOLD	253.5	259.11	264.71	270.29	275.82	281.32	286.77
COMMERCIAL	79.39	81.95	84.59	87.31	90.13	93.03	96.04
TRANSPORTATION	27.78	28.75	29.73	30.75	31.78	32.83	33.91
INDUSTRY	34.89	36.65	38.55	40.63	42.88	45.33	47.99
AGRICULTURE	7.92	9.06	10.22	11.42	12.64	13.89	15.17
TOTAL	403.48	466.41	536.8	615.56	703.57	801.3	907.71

Energy Demand, Household Sector by End-use, by Year, All Fuels

	1995	2000	2005	2010	2015	2020	2025
URBAN-ELECTRIC							
OTHER-ENDUSES	0.73	0.94	1.08	1.11	0.98	0.64	0
LIGHTING	0.25	0.38	0.54	0.74	0.99	1.28	1.64
REFRIGERATION	2.13	3.27	4.66	6.37	8.44	10.96	13.98
COOKING	46.64	62.91	77.53	89.01	95.41	94.19	82.09
AIR COOLING	0.2	0.9	2.13	4.09	6.99	11.13	16.85
URBAN-NONELEC							
COOKING	39.73	39	37.84	36.21	34.09	31.46	28.33
LIGHTING	0.03	0.05	0.08	0.1	0.13	0.16	0.18
RURAL-ELECTRIC							
OTHER-ENDUSE	0.03	0.08	0.14	0.21	0.31	0.42	0.56
REFRIGERATION	0.22	0.62	1.17	1.89	2.83	4.05	5.6
LIGHTING	0.02	0.06	0.11	0.17	0.24	0.33	0.44
COOKING	3.45	9.15	15.99	24.14	33.75	45.03	58.18
RURAL-NONELECTR							
COOKING	159.9	163.73	166.22	167.02	165.72	161.83	154.8
LIGHTING	0.17	0.24	0.32	0.41	0.51	0.62	0.72
TOTAL	253.5	281.32	307.8	331.47	350.4	362.1	363.38

d) Energy Demand, Household Sector by Fuel, by Year, All End-uses

	1995	2000	2005	2010	2015	2020	2025
ELECTRICITY	2.88	5.37	8.87	13.68	20.13	28.67	39.81
KEROSENE/JETFUEL	0.25	0.38	0.52	0.69	0.88	1.09	1.31
DIESEL/GAS OIL	0.73	0.94	1.08	1.11	0.98	0.64	0
LPG/BOTTLED GAS	0.8	1.34	1.99	2.77	3.69	4.78	6.05
FIREWOOD	133.24	133.57	132.52	129.83	125.23	118.44	109.15
CHARCOAL	83.33	107.99	132.02	153.97	171.92	183.34	184.91
URBAN FUELWOOD	24.81	24.33	23.58	22.53	21.14	19.42	17.36
TOTAL	253.5	281.32	307.8	331.47	350.4	362.1	363.38

e) Energy Demand, Commercial Sector by End-use, by Year, All Fuels

	1995	2000	2005	2010	2015	2020	2025
1.9 GOVERNEMNT SERV							
COOKING	61.8	72.5	85.1	99.9	117	138	161
LIGHTING	0	0	0	0	0	0	0
SPACE COOLING	0.02	0.02	0.03	0.04	0.05	0.06	0.07
OTHER ENDUSES	0.05	0.05	0.05	0.05	0.05	0.05	0.07
1.10 NON-GOV.SERV							
COOKING	13.4	14.8	16	17.2	18.1	18.7	18.6
SPACE COOLING	0	0.01	0.01	0.01	0.01	0.02	0.02
LIGHTING	0	0.02	0.05	0.09	0.15	0.22	0.33
OTHER END-USES	0.15	0.2	0.25	0.3	0.34	0.35	0.33
1.11 CONSTRUCTION							
MACHINERY	13.4	14.8	16	17.2	18.1	18.7	18.6
1.12 WATER SERVICES							
PUR.& PUMPING	0.31	0.44	0.62	0.88	1.25	1.76	2.5
1.13 EXPLORATION							
DRILLING & OTHE	0.59	0.85	1.22	1.74	2.5	3.57	5.12

f) Energy Demand, Commercial Sector by Fuel, by Year, All End-uses

	1995	2000	2005	2010	2015	2020	2025
ELECTRICITY	0.03	0.05	0.09	0.14	0.21	0.31	0.46
DIESEL/GAS OIL	1.19	1.67	2.36	3.33	4.71	6.65	9.39
RESIDUAL/FUELOIL	2.79	3.8	5.17	7.03	9.57	13.03	17.73
LPG/BOTTLED GAS	0.06	0.51	1.13	2	3.16	4.72	6.79
FIREWOOD	26.4	27.32	27.55	26.76	24.52	20.3	13.36
CHARCOAL	48.93	59.68	72.77	88.68	108.05	131.59	160.22
TOTAL	79.39	93.03	109.07	127.95	150.22	176.6	207.95

g) Energy Demand, Transport Sector by End-use, by Year, All Fuels

	1995	2000	2005	2010	2015	2020	2025
1.7 PASSENGERS							
PRIVATE	6.61	7.91	9.34	10.86	12.36	13.68	14.54
PUBLIC	14.46	16.97	19.7	22.55	25.36	27.85	29.59
1.8 FREIGHT							
ROAD	6.21	7.36	8.66	10.09	11.62	13.18	14.67
WATER	0.14	0.17	0.2	0.24	0.29	0.35	0.41
RAIL	0.06	0.07	0.08	0.09	0.1	0.11	0.12
AIR	0.3	0.35	0.41	0.47	0.54	0.61	0.69

h) Energy Demand, transport Sector by Fuel, by Year, All End-uses

	1995	2000	2005	2010	2015	2020	2025
GASOLINE	8	9	11	12	14	16	17
KEROSENE/JETFUEL	5	7	8	9	10	12	13
DIESEL/GAS OIL	152	178	207	236	266	293	313
RESIDUAL/FUELOIL	0	0	0	0	0	0	0
TOTAL	27.78	32.83	38.39	44.3	50.27	55.78	60.02

i) Energy Demand, Industrial Sector by End-use, by Year, All Fuels

	1995	2000	2005		2010	2015	2020
1.1 SUGAR							
PROCESS HEAT	6.49	10.98	17.83	28.14	43.51	66.19	99.45
MOTIVE POWER	0.11	0.14	0.2	0.26	0.35	0.48	0.64
1.2 FOOD& EDIBLE OIL							
PROCESS HEAT	10.16	15.56	23.45	34.63	49.75	68.67	89.01
MOTIVE POWER	0.75	1.29	2.21	3.78	6.49	11.14	19.11
1.3 TEXTILE							
PROCESS HEAT	2.95	2.95	2.95	2.95	2.95	2.95	2.95
MOTIVE POWER	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1.4 CEMENT							
PROCESS HEAT	7.26	7.26	7.26	7.26	7.26	7.26	7.26
MOTIVE POWER	0.13	0.13	0.13	0.13	0.13	0.13	0.13
1.5 OTHER INDUSTRIES							
PROCESS HEAT	0.1	0.08	0.06	0.06	0.06	0.06	0.06
MOTIVE POWER	0.66	0.66	0.66	0.66	0.66	0.66	0.66
1.6 OTHER ENDUSE							
ALL USES	6.25	6.25	6.25		6.25	6.25	6.25

j) Energy Demand, Industrial Sector by Fuel, by Year, All End-uses

	1995	2000	2005	2010	2015	2020	2025
ELECTRICITY	1.84	2.42	3.39	5.03	7.83	12.6	20.74
DIESEL/GAS OIL	6.23	6.23	6.23	6.23	6.23	6.23	6.23
RESIDUAL/FUELOIL	12.22	17.3	26.4	42.27	69.5	115.87	194.65
FIREWOOD	8.68	12.41	17.03	21.91	25.06	21.5	0
BAGASSE	5.92	6.98	7.98	8.72	8.82	7.61	3.93
TOTAL	34.89	45.33	61.02	84.17	117.45	163.82	225.56

k) Energy Demand, Agricultural Sector by End-use, by Year, All Fuels

	1995	2000	2005	2010	2015	2020	2025
MECHANIZED RAINFED OPERATION	2	3	4	5	7	8	9
IRRIGATED							
OPERATION	1	2	2	3	3	4	4
PUMPING	5	9	14	19	25	31	38
TOTAL	**8**	**14**	**21**	**28**	**35**	**43**	**51**

l) Energy Demand, Agricultural Sector by Fuel, by Year, All End-uses

	1995	2000	2005	2010	2015	2020	2025
ELECTRICITY	1	2	3	5	8	11	15
DIESEL/GAS OIL	7	12	17	22	27	32	36
RESIDUAL/FUELOIL	0	0	0	0	0	0	0
TOTAL	**8**	**14**	**21**	**28**	**35**	**43**	**51**

3) Mitigation Energy Savings Targets

a) High efficiency Air Conditioners

Mitigation cost	per GJ
Equipment efficiency improvement:	18%
Implementation starts in:	2005

Commercial - Government Subsector	1995	2005	2025
Base Case Intensity (GJ/Activity)	0.457	0.455	0.450
Stock turnover (%)	0%	0%	50%
Mitigation Case Intensity (GJ/Activity)	0.457	0.455	0.412

Commercial - Non-Government Subsector	1995	2005	2025
Base Case Intensity (GJ/Activity)	0.104	0.103	0.102
Stock turnover (%)	0%	0%	50%
Mitigation Case Intensity (GJ/Activity)	0.104	0.103	0.094

b) Compact Fluorescent Lighting

Mitigation cost	per GJ
Equipment efficiency improvement:	77%
Implementation starts in:	2005

Commercial - Government Subsector	1995	2005	2025
Base Case Intensity (GJ/Activity)	0.104	0.103	0.102
Stock turnover (%)	0%	0%	50%
Mitigation Case Intensity (GJ/Activity)	0.104	0.103	0.063

Commercial - Non-Government Subsector	1995	2005	2025
Base Case Intensity (GJ/Activity)	0.485	0.483	0.478
Stock turnover (%)	0%	0%	50%
Mitigation Case Intensity (GJ/Activity)	0.485	0.483	0.294

Residential - Urban Electric	1995	2005	2025
Base Case Intensity (GJ/Activity)	0.302	0.300	0.298
Stock turnover (%)	0%	0%	50%
Mitigation Case Intensity (GJ/Activity)	0.302	0.300	0.183

Residential - Rural Electric	1995	2005	2025
Base Case Intensity (GJ/Activity)	0.304	0.302	0.299
Stock turnover (%)	0%	0%	25%
Mitigation Case Intensity (GJ/Activity)	0.304	0.302	0.241

a) Evaporative Coolers

Mitigation cost	per Activity
Equipment efficiency improvement:	75%
Implementation starts in:	2005

Urban Electric Subsector	1995	2005	2025
Base Case Share - A/C (%)	0.04%	0.19%	0.50%
Base Case Share - coolers (%)	0%	0%	0%
Mitigation Case Share - A/C (%)	0.04%	0.19%	0.25%
Mitigation Case Share - coolers (%)	0.00%	0.00%	0.25%
A/C Intensity (GJ/Activity)	7.857	7.857	7.857
Cooler Intensity (GJ/Activity)	1.964	1.964	1.964

b) LPG cookers

Mitigation cost	per Activity
Equipment efficiency improvement:	NA
Implementation starts in:	2005

Urban Non-Electric Subsector	1995	2005	2025
Base Case Share - wood (%)	35%	30%	20%
Base Case Share - charcoal (%)	50%	43%	30%
Base Case Share - LPG (%)	15%	27%	50%
Mitigation Case Share - wood (%)	35%	30%	0%
Mitigation Case Share - charcoal (%)	50%	43%	15%
Mitigation Case Share - LPG (%)	15%	27%	85%
Wood Intensity (GJ/Activity)	21.417	21.417	21.417
Charcoal Intensity (GJ/Activity)	9.420	9.420	9.420
LPG Intensity (GJ/Activity)	3.420	3.420	3.420

Rural Electric Subsector	1995	2005	2025
Base Case Share - wood (%)	68%	58%	39%
Base Case Share - charcoal (%)	31%	31%	31%
Base Case Share - LPG (%)	1%	11%	30%
Mitigation Case Share - wood (%)	68%	58%	9%
Mitigation Case Share - charcoal (%)	31%	31%	21%
Mitigation Case Share - LPG (%)	1%	11%	67%
Wood Intensity (GJ/Activity)	21.417	21.417	21.417
Charcoal Intensity (GJ/Activity)	9.420	9.420	9.420
LPG Intensity (GJ/Activity)	3.420	3.420	3.420

Rural Non-Electric Subsector	1995	2005	2025
Base Case Share - wood (%)	68%	60%	44%
Base Case Share - charcoal (%)	31%	31%	31%
Base Case Share - LPG (%)	1%	9%	25%
Mitigation Case Share - wood (%)	68%	60%	20%
Mitigation Case Share - charcoal (%)	31%	31%	25%
Mitigation Case Share - LPG (%)	1%	9%	50%
Wood Intensity (GJ/Activity)	34.010	34.010	34.010
Charcoal Intensity (GJ/Activity)	16.000	16.000	16.000

LPG Intensity (GJ/Activity)	3.420	3.420	3.420

c) Solar Cookers

Mitigation cost	per Activity
Equipment efficiency improvement:	NA
Implementation starts in:	2005

Rural Electric Subsector	1995	2005	2025
Base Case Share - wood (%)	68%	58%	39%
Base Case Share - charcoal (%)	31%	31%	31%
Base Case Share - LPG (%)	1%	11%	30%
Base Case Share - solar (%)	0%	0%	0%
Mitigation Case Share - wood (%)	68%	58%	9%
Mitigation Case Share - charcoal (%)	31%	31%	21%
Mitigation Case Share - LPG (%)	1%	11%	67%
Mitigation Case Share - solar (%)	0%	0%	3%
Wood Intensity (GJ/Activity)	21.417	21.417	21.417
Charcoal Intensity (GJ/Activity)	9.420	9.420	9.420
LPG Intensity (GJ/Activity)	3.420	3.420	3.420
Solar Intensity (GJ/Activity)	0.062	0.062	0.062

Rural non-Electric Subsector	1995	2005	2025
Base Case Share - wood (%)	68%	58%	39%
Base Case Share - charcoal (%)	31%	31%	31%
Base Case Share - LPG (%)	1%	11%	30%
Base Case Share - solar (%)	0%	0%	0%
Mitigation Case Share - wood (%)	68%	58%	9%
Mitigation Case Share - charcoal (%)	31%	31%	21%
Mitigation Case Share - LPG (%)	1%	11%	67%
Mitigation Case Share - solar (%)	0%	0%	5%
Wood Intensity (GJ/Activity)	21.417	21.417	21.417
Charcoal Intensity (GJ/Activity)	9.420	9.420	9.420
LPG Intensity (GJ/Activity)	3.420	3.420	3.420
Solar Intensity (GJ/Activity)	0.062	0.062	0.062

d) High Efficiency Vehicle Fleets

Fuel Economy Improvements Assumed in Base Case

	Base Case	
	1995	2025
pass-km per capita	500	500
PMT per VMT	1	1
fleet vehicle share of pmt	77%	77%
population	28,500,000	61,555,000
energy share (%)	15%	17%
government diesel cars	6.555%	6.877%
government gasoline cars	0.569%	0.658%
diesel taxis	4.830%	5.290%
gasoline taxis	2.570%	3.760%
energy use (million GJ)	12.16	23.95
government diesel cars	5.71	9.93
government gasoline cars	0.52	0.95
diesel taxis	4.2	7.64
gasoline taxis	1.73	5.43
fuel economy (mpg)	11.11	13.88
government diesel cars	10.77	14.03
government gasoline cars	9.86	13.49
diesel taxis	10.79	14.03
gasoline taxis	13.40	13.49

Mitigation cost	per GJ
Equipment efficiency improvement:	100%
Implementation starts in:	2005

Passengers-Public/Private Subsector	1995	2005	2025
Base Case Intensity (GJ/Activity)			
government diesel cars	7.90	6.38	3.35
government gasoline cars	8.34	6.63	3.20
diesel taxis	7.88	6.35	3.29
gasoline taxis	6.10	5.18	3.33
Base Case Fuel Economy (mpg)			
government diesel cars	10.77	11.85	14.03
government gasoline cars	9.86	11.07	13.49
diesel taxis	10.79	11.87	14.03
gasoline taxis	13.40	13.43	13.49
Efficiency Improvement (M/B)			
government diesel cars	0	0	2
government gasoline cars	0	0	2
diesel taxis	0	0	2
gasoline taxis	0	0	2
Mitigation Case Fuel Economy (mpg)			
government diesel cars	10.77	11.85	28.06
government gasoline cars	9.86	11.07	26.98
diesel taxis	10.79	11.87	28.05
gasoline taxis	13.40	13.43	26.97

Stock turnover (%)	0%	0%	50%
Mitigation Case Intensity (GJ/Activity)			
government diesel cars	7.90	6.38	2.51
government gasoline cars	8.34	6.63	2.40
diesel taxis	7.88	6.35	2.47
gasoline taxis	6.10	5.18	2.50

e) High Efficiency Electric Motors

Mitigation cost	per GJ
Equipment efficiency improvement:	15%
Implementation starts in:	2005

Sugar Subsector	1995	2005	2025
Base Case Intensity (GJ/Activity)	0.251	0.243	0.227
Stock turnover (%)	0%	0%	50%
Mitigation Case Intensity (GJ/Activity)	0.251	0.243	0.220

Food Subsector	1995	2005	2025
Base Case Intensity (GJ/Activity)	4.283	4.283	4.283
Stock turnover (%)	0%	0%	50%
Mitigation Case Intensity (GJ/Activity)	4.283	4.283	3.962

Textile Subsector	1995	2005	2025
Base Case Intensity (GJ/Activity)	2.488	2.488	2.488
Stock turnover (%)	0%	0%	50%
Mitigation Case Intensity (GJ/Activity)	2.488	2.488	2.301

Cement Subsector	1995	2005	2025
Base Case Intensity (GJ/Activity)	0.531	0.531	0.531
Stock turnover (%)	0%	0%	50%
Mitigation Case Intensity (GJ/Activity)	0.531	0.531	0.491

Other Industries Subsector	1995	2005	2025
Base Case Intensity (GJ/Activity)	28.999	28.999	28.999
Stock turnover (%)	0%	0%	50%
Mitigation Case Intensity (GJ/Activity)	28.999	28.999	26.824

4) Energy Demand Summary, Mitigation Case

The following tables summarize the consumption of energy in the Mitigation Case over the 1995-2025 period, in increments of 5 years. A total of 12 tables are provided, 2 for each of the five demand sectors, and 2 describing energy demand across all sectors.

a) Energy Demand, by Fuel by Year, All Sectors

	1995	2000	2005	2010	2015	2020	2025
ELECTRICITY	5.37	9.19	14.72	22.49	33.12	47.57	67.3
GASOLINE	8.2	9.75	11.44	13.21	14.92	16.38	17.22
KEROSENE/JETFUEL	2.35	2.91	3.54	4.23	4.95	5.63	6.2
DIESEL/GAS OIL	32.85	41.42	50.47	59.82	69.24	78.44	86.98
RESIDUAL/FUELOIL	15.09	21.27	31.98	48.66	75.91	120.11	191.6
LPG/BOTTLED GAS	0.86	2.34	4.53	7.04	10.16	14.04	18.84
FIREWOOD	168.32	172.89	176.26	162.85	142.69	110.07	53.01
CHARCOAL	132.26	173.37	213.57	247.77	275.46	292.63	294.08
BAGASSE	24.81	24.33	23.58	22.53	21.14	19.42	17.36
SOLAR	5.92	6.39	6.64	6.56	5.94	4.51	1.82
URBAN FUELWOOD	0	0	0	0	0.01	0.01	0.01
TOTAL	403.48	471.26	543.95	600.89	657.58	710.92	754.44

b) Energy Demand, by Sector by Year, All Sectors

	1995	2000	2005	2010	2015	2020	2025
HOUSEHOLD	253.5	287.3	317.47	322.54	315.28	291.17	244.5
COMMERCIAL	79.39	92.51	107.82	125.72	146.7	171.36	200.47
TRANSPORTATION	27.78	32.73	38.12	43.77	49.35	54.27	57.65
INDUSTRY	34.89	44.82	60.01	81.17	111.01	151.11	201.01
AGRICULTURE	7.92	13.89	20.52	27.68	35.24	43.01	50.8
TOTAL	403.48	471.26	543.95	600.89	657.58	710.92	754.44

c) Energy Demand, Household Sector by End-use, by Year, All Fuels

	1995	2000	2005	2010	2015	2020	2025
URBAN-ELECTRIC							
OTHER-ENDUSES	0.73	0.94	1.08	1.11	0.98	0.64	0
LIGHTING	0.25	0.38	0.54	0.69	0.84	1	1.15
REFRIGERATION	2.13	3.27	4.66	6.37	8.44	10.96	13.98
COOKING	46.64	60.48	70.55	73.69	67.36	47.67	9.67
AIR COOLING	0.2	0.58	1.21	2.43	4.26	6.88	10.53
URBAN-NONELEC							
COOKING	39.73	36.64	32.91	28.55	23.61	18.18	12.41
LIGHTING	0.03	0.05	0.08	0.1	0.13	0.16	0.18
RURAL-ELECTRIC							
OTHER-ENDUSE	0.03	0.08	0.14	0.21	0.31	0.42	0.56
REFRIGERATION	0.22	0.62	1.17	1.89	2.83	4.05	5.6
LIGHTING	0.02	0.06	0.11	0.16	0.22	0.28	0.36
COOKING	3.45	8.46	13.51	18.35	22.63	25.87	27.46
RURAL-NONELECTR							
COOKING	159.9	161.78	162.19	165.73	167.27	166.23	161.87
LIGHTING	0.17	0.24	0.32	0.41	0.51	0.62	0.72
TOTAL	253.5	273.57	288.47	299.69	299.4	282.95	244.5

d) Energy Demand, Household Sector by Fuel, by Year, All End-uses

	1995	2000	2005	2010	2015	2020	2025
ELECTRICITY	2.88	5.05	7.96	11.96	17.24	24.09	32.92
KEROSENE/JETFUEL	0.25	0.38	0.52	0.69	0.88	1.09	1.31
DIESEL/GAS OIL	0.73	0.94	1.08	1.11	0.98	0.64	0
LPG/BOTTLED GAS	0.8	1.9	3.55	5.18	7.11	9.38	12.05
FIREWOOD	133.24	133.3	131.56	114.8	95.06	72.39	46.99
CHARCOAL	83.33	100.98	114.49	138.84	153.73	154.21	133.86
SOLAR	24.81	24.33	23.58	22.53	21.14	19.42	17.36
URBAN FUELWOOD	0	0	0	0	0.01	0.01	0.01
TOTAL	253.5	273.57	288.47	299.69	299.4	282.95	244.5

Energy Demand, Commercial Sector by End-use, by Year, All Fuels

	1995	2000	2005	2010	2015	2020	2025
GOVERNEMNT SERV							
COOKING	61.78	72.02	83.95	97.83	113.98	132.76	154.59
LIGHTING	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SPACE COOLING	0.02	0.02	0.03	0.03	0.04	0.05	0.07
OTHER ENDUSES	0.05	0.05	0.05	0.05	0.05	0.05	0.07
NON-GOV.SERV							
COOKING	13.42	14.75	16.04	17.21	18.14	18.68	18.63
SPACE COOLING	0.00	0.01	0.01	0.01	0.01	0.01	0.02
LIGHTING	0.00	0.02	0.05	0.08	0.12	0.16	0.20
OTHER END-USES	0.15	0.2	0.25	0.3	0.34	0.35	0.33
CONSTRUCTION							
MACHINERY	3.07	4.18	5.69	7.74	10.53	14.34	19.51
WATER SERVICES							
PUR.& PUMPING	0.31	0.44	0.62	0.88	1.25	1.76	2.5
EXPLORATION							
DRILLING & OTHE	0.59	0.85	1.22	1.74	2.5	3.57	5.12
TOTAL	79.39	92.55	107.91	125.89	146.96	171.75	201.02

f) Energy Demand, Commercial Sector by Fuel, by Year, All End-uses

	1995	2000	2005	2010	2015	2020	2025
ELECTRICITY	0.03	0.05	0.09	0.13	0.18	0.24	0.32
DIESEL/GAS OIL	1.19	1.67	2.36	3.33	4.71	6.65	9.39
RESIDUAL/FUELOIL	2.79	3.8	5.17	7.03	9.57	13.03	17.73
LPG/BOTTLED GAS	0.06	0.55	1.23	2.16	3.42	5.11	7.34
FIREWOOD	26.4	26.8	26.3	24.54	21.03	15.13	6.02
CHARCOAL	48.93	59.68	72.77	88.68	108.05	131.59	160.22
TOTAL	79.39	92.55	107.91	125.89	146.96	171.75	201.02

Energy Demand, Transport Sector by End-use, by Year, All Fuels

	1995	2000	2005	2010	2015	2020	2025
PASSENGERS							
PRIVATE	6.61	7.9	9.31	10.8	12.26	13.52	14.28
PUBLIC	14.46	16.88	19.46	22.08	24.54	26.5	27.47
FREIGHT							
ROAD	6.21	7.36	8.66	10.09	11.62	13.18	14.67
WATER	0.14	0.17	0.2	0.24	0.29	0.35	0.41
RAIL	0.06	0.07	0.08	0.09	0.1	0.11	0.12
AIR	0.3	0.35	0.41	0.47	0.54	0.61	0.69
TOTAL	27.78	32.73	38.12	43.77	49.35	54.27	57.65

g) Energy Demand, transport Sector by Fuel, by Year, All End-uses

	1995	2000	2005	2010	2015	2020	2025
GASOLINE	8.2	9.75	11.44	13.21	14.92	16.38	17.22
KEROSENE/JETFUEL	2.1	2.54	3.02	3.54	4.07	4.55	4.9
DIESEL/GAS OIL	17.4	20.36	23.56	26.92	30.24	33.22	35.39
RESIDUAL/FUELOIL	0.08	0.09	0.1	0.11	0.12	0.13	0.14
TOTAL	27.78	32.73	38.12	43.77	49.35	54.27	57.65

Energy Demand, Industrial Sector by End-use, by Year, All Fuels

	1995	2000	2005	2010	2015	2020	2025
SUGAR							
PROCESS HEAT	6.49	11.02	18.01	27.89	41.98	61.81	89.39
MOTIVE POWER	0.11	0.15	0.2	0.27	0.36	0.47	0.62
FOOD& EDIBLE OIL							
PROCESS HEAT	10.16	15.58	23.55	34.48	48.72	65.23	79.64
MOTIVE POWER	0.75	1.29	2.21	3.71	6.25	10.51	17.68
TEXTILE							
PROCESS HEAT	2.95	2.95	2.95	2.84	2.73	2.62	2.51
MOTIVE POWER	0.04	0.04	0.04	0.03	0.03	0.03	0.03
CEMENT							
PROCESS HEAT	7.26	7.26	7.26	7	6.73	6.46	6.19
MOTIVE POWER	0.13	0.13	0.13	0.13	0.13	0.12	0.12
OTHER INDUSTRIES							
PROCESS HEAT	0.1	0.1	0.1	0.09	0.09	0.09	0.09
MOTIVE POWER	0.66	0.66	0.66	0.65	0.63	0.62	0.61
OTHER ENDUSE							
ALL USES	6.25	6.25	6.25	6.25	6.25	6.25	6.25
TOTAL	34.89	45.41	61.34	83.33	113.89	154.21	203.12

h) Energy Demand, Industrial Sector by Fuel, by Year, All End-uses

	1995	2000	2005	2010	2015	2020	2025
ELECTRICITY	1.84	2.42	3.39	4.95	7.56	11.93	19.23
DIESEL/GAS OIL	6.23	6.23	6.23	6.23	6.23	6.23	6.23
RESIDUAL/FUELOIL	12.22	17.38	26.71	41.51	66.21	106.95	173.73
FIREWOOD	8.68	12.41	17.03	21.91	25.06	21.5	0
BAGASSE	5.92	6.98	7.98	8.72	8.82	7.61	3.93
TOTAL	34.89	45.41	61.34	83.33	113.89	154.21	203.12

k) Energy Demand, Agricultural Sector by End-use, by Year, All Fuels

	1995	2000	2005	2010	2015	2020	2025
MECHANIZED RAINFED OPERATION	2	3	4	5	7	8	9
IRRIGATED OPERATION	1	2	2	3	3	4	4
PUMPING	5	9	14	19	25	31	38
TOTAL	**8**	**14**	**21**	**28**	**35**	**43**	**51**

l) Energy Demand, Agricultural Sector by Fuel, by Year, All End-uses

	1995	2000	2005	2010	2015	2020	2025
ELECTRICITY	1	2	3	5	8	11	15
DIESEL/GAS OIL	7	12	17	22	27	32	36
RESIDUAL/FUELOIL	0	0	0	0	0	0	0
TOTAL	**8**	**14**	**21**	**28**	**35**	**43**	**51**

5) Cost and Performance Characteristics of New Electric Supply Technologies

Technology	First Year Avail	Size (MW)	Leadtime (Year)	Overnight Capital Costs (1) In 1999 ($1998/kW)	Variable O&M (1998 Mills/kWhr)	Fixed O&M ($1998/kW)	Heatrate First-of-a-kind (Btu/kWhr)	Heatrate Nth-of-a-kind (Btu/kWhr)
Scrubbed Coal	1997	400	4	1,102	3.33	23.03	9,585	9,087
Integrated Gas Comb Cycle	1997	428	4	1,315	0.79	32.13	8,470	6,968
Gas/Oil Steam Turbine	1997	300	2	1,012	0.51	30.7	9,500	9,500
Conv Gas/Oil Comb Cycle	1997	250	3	449	0.51	15.35	8,030	7,000
Adv Gas/Oil Comb Cycle	1997	400	3	580	0.51	14.23	6,985	6,350
Conventional Combustion Turbine	1998	160	2	332	0.1	6.35	11,900	10,600
Advanced Combustion Turbine	1997	120	2	465	0.1	9.01	9,700	8,000
Fuel Cells	2001	10	2	2,163	2.05	14.74	6,000	5,361
Advanced Nuclear	2001	600	4	2,390	0.41	56.29	10,400	10,400
Biomass	2001	100	4	1,877	5.32	44	9,224	8,219
MSW (2)	1996	30	1	4,424	5.532	0	16,000	16,000
Geothermal (3)	1997	50	4	1,621	0	85.9	32,391	N/A
Wind	1997	50	3	993	0	25.92	N/A	N/A
Solar Thermal (4,5)	1997	100	3	3,059	0	46.58	N/A	N/A
Photovoltaic (5)	1998	5	2	4,836	0	9.82	N/A	N/A
Conventional Hydro (6)	1997	NA	3	3,058	4.5	14.3	NA	NA
Isolated diesel (7)	1997	NA	0	283	0	37.1	16,000	16,000

1 Overnight capital cost (i.e., excluding interest charges) plus project contingencies, excluding regional multipliers (See Tables 38 and 39). These estimates are costs of new projects as of January 1, 1999.

2 Because municipal solid waste (MSW) does not compete with other technologies in the model, these values are used only in calculating the average costs of electricity.

3 Because geothermal cost and performance parameters are specific for each of the 51 sites in the database, the Nth-of-a-kind capital cost and heat rate are averages for the capacity built in 2000.

4 Solar thermal is assumed to operate economically only in Electricity Market Module regions 2, 5, and 10-13, that is, West of the Mississippi River, because of its requirement for significant direct, normal insolation.

5 Capital costs for solar technologies do not include the 10 percent investment tax credit.

6 Capital costs for conventional hydro is from AEO96 assumptions for California, adjusted from 1987$ to 1998$.

7 From carbon backcasting study for the World Bank (Morocco energy loan) O&M = Operation and maintenance.

Note: The first year that a new technology can be built is equal to the first year completed plus the lead time.

Sources: Most values are derived by the Energy Information Administration, Office of Integrated Analysis and Forecasting from analysis of reports and discussions with various sources from industry, government, and the National Laboratories, with the following specific sources — Solar Thermal: California Energy Commission Memorandum, Technology Characterization for ER94, August 6, 1993. Photovoltaic: Technical Assessment Guide-Electric Power Research Institute (EPRI-TAG1993). MSW: EPRI-TAG 1993.

6) Base Case Electric Supply Plan

a. Generation (TWh)

	1995	2000	2005	2010	2015	2020	2025
hydro	0.97	0.77	0.74	0.67	0.62	0.63	0.78
ex. oil steam	0.63	0.52	0.49	0.44	0.4	0.4	0.51
new oil steam	0	0.95	2.65	2.39	3.83	7.69	11.18
gas turbine	0.07	0.21	0.19	0.18	0.16	0.16	0.2
diesel	0.11	0	0	0	0	0	0
isolated diesil	0.08	0.25	0.24	0.22	0.21	0.21	0.25
combined cycle	0	0	0	0	2.16	2.88	4.66
New Hydro	0	0	0	3.05	2.86	2.89	3.57
new gas turbine	0	0.42	0.93	1.32	2.21	3.34	4.99
new isolated die	0	0.19	0.19	0.17	0.16	0.17	0.19
TOTAL	1.86	3.3	5.43	8.44	12.61	18.36	26.33

Capacity (MW)

	1995	2000	2005	2010	2015	2020	2025
Hydro	307.7	307.7	307.7	307.7	307.7	307.7	307.7
Ex. Oil Steam	165	165	165	165	165	165	165
New Oil Steam	0	300	900	900	1600	3200	3600
Gas Turbine	66	66	66	66	66	66	66
Diesel	79.5	79.5	79.5	79.5	79.5	79.5	79.5
Isolated Diesil	108.5	108.5	108.5	108.5	108.5	108.5	108.5
Wind	0	0	0	0	0	0	0
Solar	0	0	0	0	0	0	0
Combined Cycle	0	0	0	0	900	1200	1500
New Hydro	0	0	0	1407.7	1407.7	1407.7	1407.7
New Gas Turbine	0	150	350	550	1000	1500	1800
New Isolated Die	0	84	84	84	84	84	84
Total	726.7	1260.7	2060.7	3668.4	5718.4	8118.4	9118.4

Fuel Use (million GJ)

	1995	2000	2005	2010	2015	2020	2025
NATURAL GAS	0	0	0	0	16.87	21.62	34.22
DIESEL/GAS OIL	3.66	14.93	20.96	25.08	33.88	45.8	65.89
RESIDUAL/FUELOIL	6.16	14.04	29.81	26.92	40.15	76.68	110.88
WIND	0	0	0	0	0	0	0
SOLAR	0	0	0	0	0	0	0
HYDRO	3.5	2.77	2.68	13.38	12.54	12.68	15.67
TOTAL	13.32	31.74	53.45	65.38	103.44	156.79	226.65

7) Mitigation Case Electric Supply Plan

Generation (TWh)

	1995	2000	2005	2010	2015	2020	2025
hydro	0.97	0.82	0.89	0.72	0.81	0.78	0.92
ex. oil steam	0.63	0.60	0.66	0.49	0.56	0.52	0.70
new oil steam	0.00	0.00	1.61	1.78	2.03	1.88	2.56
gas turbine	0.07	0.24	0.27	0.20	0.22	0.21	0.28
diesel	0.11	0.00	0.00	0.00	0.00	0.00	0.00
isolated diesil	0.08	0.26	0.27	0.24	0.25	0.25	0.28
wind	0.00	0.00	0.00	0.00	0.00	0.00	0.11
solar	0.00	0.00	0.00	0.00	0.00	0.00	0.08
combined cycle	0.00	0.00	0.00	0.00	2.71	8.14	12.35
New Hydro	0.00	0.00	0.00	3.29	3.69	3.57	4.21
new gas turbine	0.00	1.07	1.20	0.92	1.03	0.97	1.65
new isolated die	0.00	0.20	0.21	0.18	0.20	0.19	0.21
TOTAL	1.86	3.19	5.11	7.81	11.50	16.52	23.37
Generation Savings	0.00	0.11	0.32	0.63	1.11	1.84	2.96

a) Capacity (MW)

	1995	2000	2005	2010	2015	2020	2025
hydro	308	308	308	308	308	308	308
ex. oil steam	165	165	165	165	165	165	165
new oil steam	0	0	400	600	600	600	600
gas turbine	66	66	66	66	66	66	66
diesel	80	80	80	80	80	80	80
isolated diesil	109	109	109	109	109	109	109
wind	0	0	50	100	250	300	400
solar	0	0	0	0	150	150	300
combined cycle	0	0	0	0	800	2,600	2,900
New Hydro	0	0	0	1,408	1,408	1,408	1,408
new gas turbine	0	0	500	500	1,050	1,500	1,700
new isolated die	0	0	84	84	84	84	84
TOTAL	727	727	1,761	3,418	5,068	7,368	8,118
Capacity Reduction	0	0	300	250	650	750	1,000

b) Fuel Consumption (million GJ)

	1995	2000	2005	2010	2015	2020	2025
NATURAL GAS	0	0	0	0	18.78	55.31	82.52
DIESEL/GAS OIL	3.66	23.7	25.92	20.69	22.89	21.9	29.68
RESIDUAL/FUELOIL	6.16	5.82	25.75	26.18	29.86	27.58	37.51
WIND	0	0	0	0	0	0	0.41
SOLAR	0	0	0	0	0	0	0.17
HYDRO	3.5	2.96	3.22	14.41	16.17	15.68	18.49
TOTAL	13.32	32.48	54.89	61.28	87.7	120.47	168.77
Fuel Savings	0	-0.74	-1.44	4.1	15.74	36.32	57.88

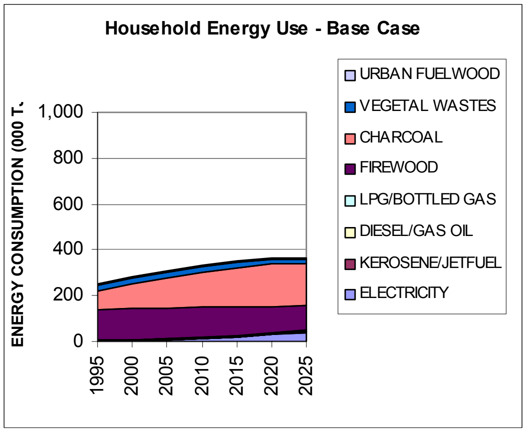
8) Base Case Carbon Dioxide Emissions (million tonnes)

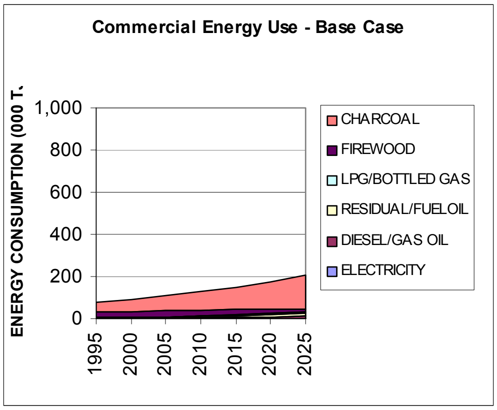
		1995	2000	2005	2010	2015	2020	2025
CARBON DIOXIDE	Household	0.13	0.19	0.26	0.32	0.39	0.46	0.52
(non-biogenic)	Commercial	0.31	0.45	0.65	0.92	1.30	1.82	2.52
	Transport	2.00	2.36	2.76	3.18	3.61	4.00	4.30
	Industrial	1.39	1.78	2.48	3.70	5.78	9.34	15.37
	Agricultural	0.54	0.90	1.27	1.63	1.99	2.33	2.64
	Electric	0.72	1.71	3.00	2.79	5.66	9.39	13.76
	Total	5.07	7.38	10.41	12.55	18.73	27.33	39.11
CARBON DIOXIDE	Household	24.29	26.66	28.80	30.53	31.64	31.84	30.79
(biogenic)	Commercial	7.27	8.40	9.70	11.17	12.84	14.73	16.86
	Transport	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Industrial	1.91	2.46	3.08	3.68	4.00	3.44	0.72
	Agricultural	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Electric	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total	33.47	37.52	41.58	45.38	48.48	50.01	48.37
CARBON DIOXIDE	Household	24.42	26.85	29.06	30.85	32.03	32.30	31.31
(all)	Commercial	7.58	8.85	10.35	12.09	14.14	16.55	19.38
	Transport	2.00	2.36	2.76	3.18	3.61	4.00	4.30
	Industrial	3.30	4.24	5.56	7.38	9.78	12.78	16.09
	Agricultural	0.54	0.90	1.27	1.63	1.99	2.33	2.64
	Electric	0.72	1.71	3.00	2.79	5.66	9.39	13.76
	Total	38.55	44.91	51.99	57.93	67.21	77.35	87.49

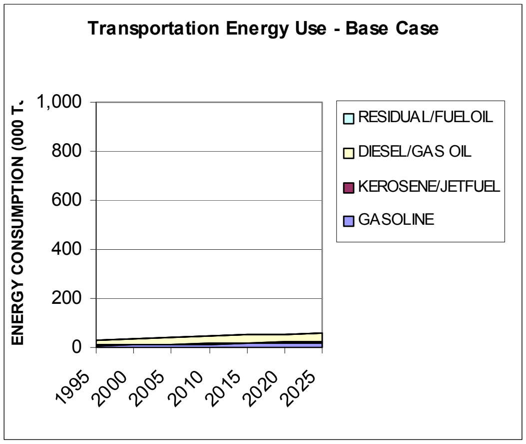
9) Mitigation Case Carbon Dioxide Emissions (million tonnes)

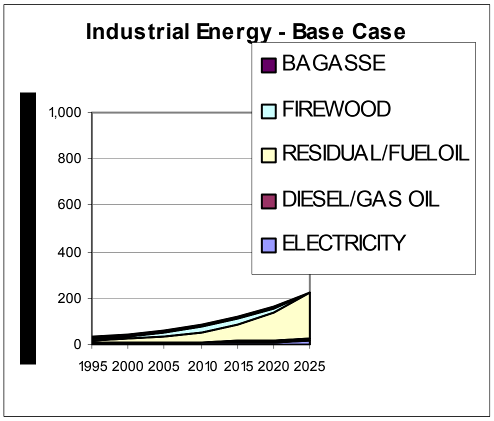
		1995	2000	2005	2010	2015	2020	2025
CARBON DIOXIDE	Household	0.13	0.23	0.36	0.49	0.63	0.78	0.94
(non-biogenic)	Commercial	0.31	0.45	0.66	0.94	1.32	1.84	2.56
	Transport	2.00	2.35	2.74	3.14	3.54	3.90	4.14
	Industrial	1.39	1.79	2.50	3.64	5.53	8.65	13.77
	Agricultural	0.54	0.90	1.27	1.63	1.99	2.33	2.64
	Electric	0.72	2.18	3.81	3.45	4.87	6.53	9.25
	Total	5.09	7.90	11.34	13.29	17.88	24.03	33.30
CARBON DIOXIDE	Household	24.29	25.89	26.86	27.41	26.70	24.25	19.46
(biogenic)	Commercial	7.27	8.35	9.58	10.96	12.51	14.24	16.16
	Transport	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Industrial	1.91	2.46	3.08	3.68	4.00	3.44	0.72
	Agricultural	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Electric	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total	33.47	36.70	39.52	42.05	43.21	41.93	36.34
CARBON DIOXIDE	Household	24.42	26.12	27.22	27.90	27.33	25.03	20.40
(all)	Commercial	7.58	8.80	10.24	11.90	13.83	16.08	18.72
	Transport	2.00	2.35	2.74	3.14	3.54	3.90	4.14
	Industrial	3.30	4.25	5.58	7.32	9.53	12.09	14.49
	Agricultural	0.54	0.90	1.27	1.63	1.99	2.33	2.64
	Electric	0.72	2.18	3.81	3.45	4.87	6.53	9.25
	Total	38.56	44.60	50.86	55.34	61.09	65.96	69.64

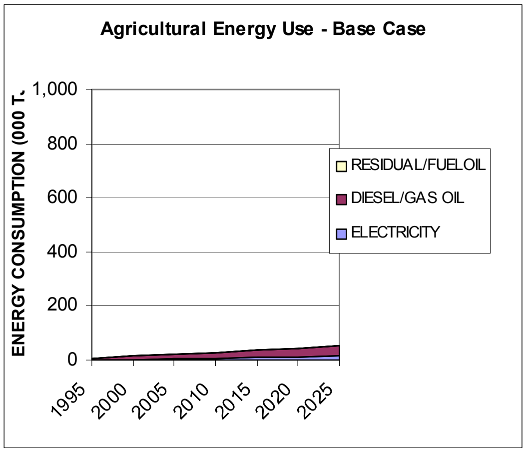
10) Energy Use Summary Charts – Base Case



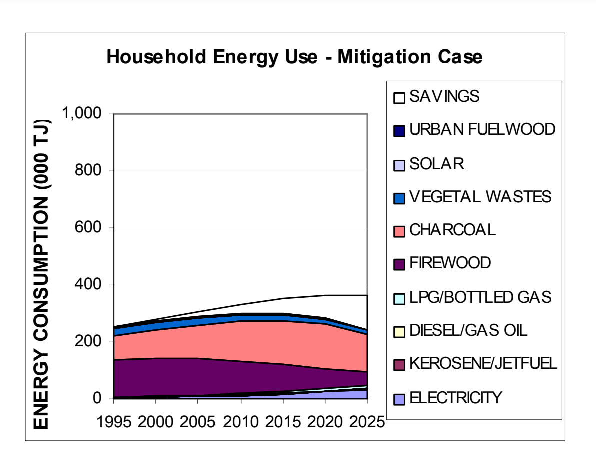


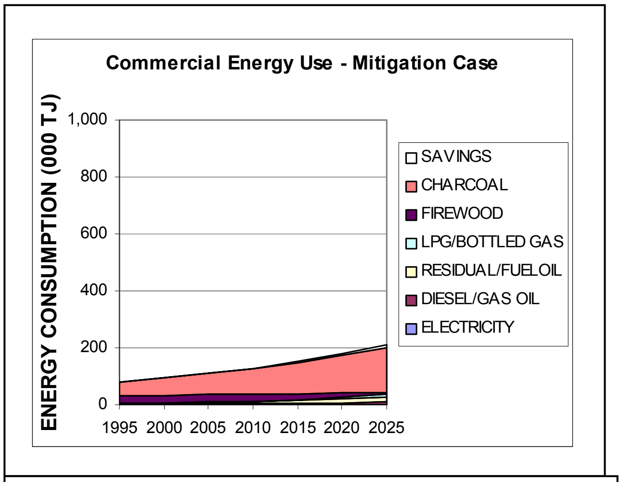


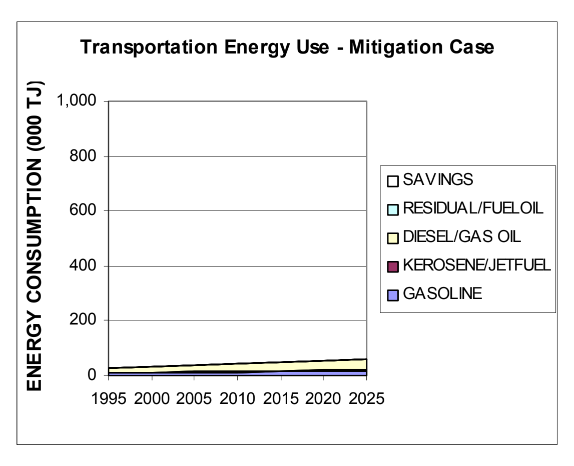


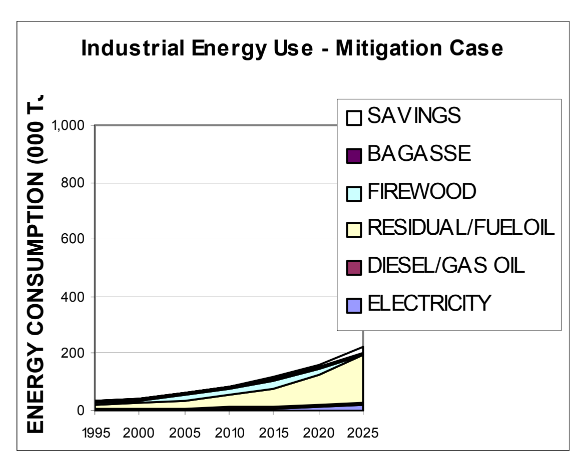


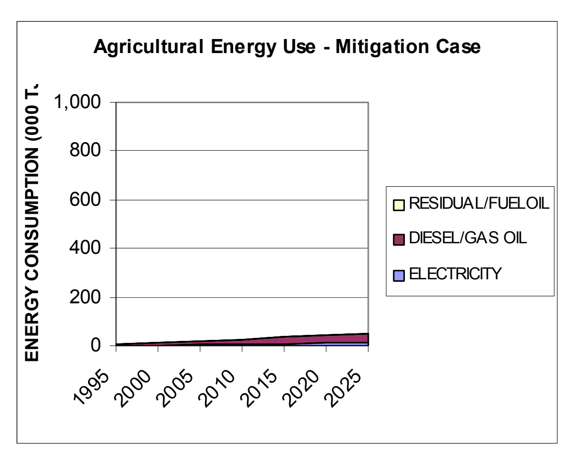
11) Energy Use Summary Charts – Mitigation Case











6. Greenhouse Gas Mitigation Options in the Non-Energy Sectors

6.1 Introduction

Sudan is the largest country in Africa (250 million ha). It lies within the tropical zone between latitudes 3º and 22º North and longitudes 22º and 38º East. It is of vast plains interrupted by few widely separated hills and mountains. The Nile River and its tributaries traverse the Sudan from North to South.

Rainfall varies from zero in the northern desert to about 1,500 mm in the South. Mean daily temperatures are fairly high throughout Sudan; mean daily maximum in the hottest month is above 40º C through the northern half of the country, and generally in the high 30sº C throughout the rest of the country except the highlands along the southern border. The mean daily minimum generally ranges from 10º - 20º C.

The major soil types are sandy soils west of the Nile, heavy clay in the eastern and central part and Nuba Mountains, the red lateritic soil of the southern part, and the soil of volcanic origin in Jebel Marra in the South West. Apart from this there are large areas covered with alluvial deposits such as Gash Delta lands and along, the Nile and numerous watercourses scattered throughout the country.

Sudan has been classified (Harrison and Jackson, 1958) into five vegetation zones that reflect the country's soil and climatic diversity. They are as follows:

- **North to South Desert Zone:** (0 – 75 mm);
- **Semi desert:** (75 – 300 mm);
- **Low Rainfall Savannah:** (300 – 800 mm);
- **High Rainfall Savannah:** (800 – 1,800 mm); and
- **Flood Plains and Montane Vegetation:** (500 – 2,000 mm).

The 1993 census estimated Sudan population at 25.7 million with growth rate of about 2.7%; average population density estimated at seven people per sq. km, though the density is much higher at 55 persons per sq. km. on arable land. The areas of highest concentrations are around Khartoum and along the Blue Nile south of Khartoum. The growth of the urban population has risen from 8.3% in 1955, to 20.2% in 1983, to 30% in 1993.

Despite being rich in natural resources, the country has one of the least developed economies, with an estimated per capita income of $250 in 1994. Sudanese economy suffered from poor performance, which resulted in chronic budget deficits. Agricultural sector is the backbone of the economy, contributing by 48.7% of GDP with forestry (12%), livestock (20%-22%) and fisheries as the major sub sectors.

The diversity in the soils and climate of the Sudan underlie the different patterns in landuse. In the North, land use is characterized by highly mobile pastoral systems, while the central part of Sudan and much of the South is characterized by sedentary Agro-pastoral system (small-scale agriculture together with some animal husbandry). Large-scale agriculture and irrigated forms occur in the central and eastern region in close proximity to the river basins.

In Sudan different land areas are varied from sector to another. Currently, 2,619,000 hectares of the country are used as dense forests, 4,690,000 hectares are woodland, 581,000 hectares are forest plantations, and 44,692,500 hectares are the savanna. The desert area occupies 798,784,200 hectares. The agricultural land is almost 17,242,140 hectares of the country area.

Land tenure system in Sudan greatly influences the exploitation of natural resources. The 1970 Unregistered Land Act of Sudan stated that all unregistered land is state owned, but local people have rights to its benefits. This applies to rangelands and other uncultivated or non-residential lands. Although the customary systems of land tenure defined the use of these communal lands to some extent, the scarcity of land based resources is due to some development policies conflicts on landuse have occurred in many areas. However, the current 10-year Comprehensive National Strategy (CNS) 1992 – 2002, called for the rational use of natural resources and environmental protection. Also, it 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.

6.2 Land Use Problems in Sudan

Land use issues in Sudan face many problems due primarily to a lack of an adequate policy framework. Although each sector has its own policy, the absence of integration between these policies, the interference and the piece meal planning and implementation of programmes has created many conflicts, e.g. the expansion of agricultural area on the forest and range land areas.

Additional factors include the absence of unified legislation and absence of useful high-resolution land use maps of the country. The current laws and policies may not be adequate to protect the natural resources because of their sectoral focus and lack of the necessary coordination between the sectors (forest, agriculture, range, and protected lands). Other factors include inadequate consideration of the socio-economic factors, which play a vital role in land management and conversion, as well as weak implementation of existing legislation and policies.

The above listed factors play an important role in the resulting environmental problems such as overgrazing and over cultivation that leads to tree felling and the presence of marginal population. This leads to social problems like reduced land productivity, poverty, and unsustainable rural-urban migration.

6.3 Types of Land Use

6.3.1 Forestry Lands

Forestry is very important in satisfying basic needs of societies at all stages of development. Forest products in the form of wood fuel, charcoal, construction poles, timber, gums, leaves, and native and processed medicines are still in demand at varying levels. The means by which these products are obtained has varying impacts on the role played by forestry in environmental protection.

Historical data of the resource assessments in Sudan indicates declining trend in the forest area (Harrison & Jackson, 1958; FAO, 1990 and FNC, 1998). This was mainly attributed to expansion of agriculture, grazing and building and fuel wood consumption. The total demand for forest products was estimated at 16.0 million cubic meters (FNC, 1994). On the supply side, the annual increment in forest stock is estimated at 11.0 million cubic meters (FNC, 1998). This clearly indicates the annual loss in the biomass stock (i.e., a net loss of 5 million cubic meters per year). Elsiddig (1999) estimated that about 455,000 hectares of forestland is being cleared annually for agriculture and other purposes. Part of the cleared biomass is used as fuel wood, while a significant portion is burned on-site. The Comprehensive National Strategy (1992-2002) called for reserving 25% of the country area for forest, rangeland and wildlife reserves. Despite the early start of reserve process and the supportive policies up to 1995, the total forest area being reserved is only about 4% of the country area. With regard to forest management, only about 1.5% of the total reserved area is actually under proper forest management and these are solely plantation forests.

6.3.2 Rangelands

In 1997, range lands covered an estimated area of 117 million hectares (RPA, 1993). Nearly 80% of all rangelands are located in semi-desert and low rainfall savanna ecological zones that are characterized by variable and unpredictable rainfall.

Rangelands in Sudan contribute substantially to income and subsistence of a large sector of the population who are either pastoralists or agro-pastoralists by providing an important feed resource. It supplies about 80% of the total feed requirement of national herds; as well as providing a habitat for wildlife. Also, rangelands play a vital role in soil and water protection, biological diversity and ecological balance. Several factors have adversely affected this resource, as follows:

- **Uncontrolled burning**: In semi-desert rangelands in western Sudan, fires annually burn 30%-50% of the land surface, destroying an estimated 25%-30% of net primary production (Bunderson, 1986). This result in CO_2 and other GHG emissions.
- **Overgrazing**: In Traditional Pastoral Systems, which constitutes about 90% of the national herd, concentration of large livestock population around perennial sources of water and wet season grazing areas often result in overgrazing. Concentration of the grazers also results in an increase of methane gas emission.
- **Development policies**: Absence of clear-cut policy towards pastoral resource coupled with a sectoral approach in development planning often result in a misallocation of land resources, such as expansion in cash crops production in the clay plains. Under mechanized and traditional rainfed agriculture, much of the expansion in cropped areas comes at the expense of forests and rangelands.
- **Legislation:** The absence of legislation that protects rangelands -- and of effective policies that govern their management and utilization -- is also an important factor in the deterioration and/or misuse of this resource.
- **Social Aspects:** Traditional management systems organized and controlled by local administration and its institutions, by laws and traditions, have succeeded in maintaining some degree of balance between range resource and level of utilization. Abolishing this effective system without a sound alternative will contribute to the deterioration of rangelands.
- **Natural hazards:** Frequent occurrence of drought in the Sahel during the last decades and rainstorms/floods during 1988 affected the pastoral sector, and caused the death of large numbers of livestock and migration of pastoralists.

The factors highlighted above have resulted in serious environmental impacts, as summarized below:

- Reduction of rangeland area, estimated at about 19.6% of total rangeland area (Range and Pasture Administration, 1993).
- Shift in botanical composition away from palatable and diverse forage species. The resulting poor forage has low levels of digestibility resulting in greater methane gas emissions per unit feed intake.
- Replacement of perennial grasses by annual grasses and, in some cases, poisonous species.
- Reduction of forage production per unit area as a result of land deterioration.

These impacts have in turn resulted in several adverse secondary impacts such as soil erosion, land degradation and desertification in some cases. Consequently, rangelands in Sudan have been steadily losing their capacity to sequester carbon.

6.3.3 Protected Land

Protected areas in Sudan are mainly wildlife reserves, with an estimated total area of 3,125,200 hectares (1,186,000 hectares as sanctuaries and 2,166,000 hectares as national parks) covering about 1.3% of the land area. Sudan furnishes appropriate ground for the existence of a wide range of wildlife.

Wildlife has received little attention in Sudan although it plays an important socio-economic role in the society. Protected areas in Sudan have been subjected to serious misuse that has resulted in diminishing of the area, decline in the number of animals and in the extreme leading to extinction of some species while more are endangered (Abd El hamid, 1999).

Between latitude 10-22^o N, Sudan has many wildlife sanctuaries and national parks. Among the national parks, El Dinder receives the most attention from government, although its area has been diminishing due to expansion of agriculture, pastoral activities, hunting and deforestation – all of which have contributed to a steady decline of wildlife. However, the reserved and gazetted areas, owned by the Wildlife Authority, are considered well-protected land.

Recently, an important GEF project has been started in El Dinder area, with the aim to balance considerations for the park, the buffer zone and the needs of local communities. With regard to future plans, a number of areas were proposed (see Table 6.1) since a long time but it is unclear when the process of declaring them protected areas will be completed.

Table 6.1: Proposed Protected Area between Latitude 10° – 22° N

Type	Proposed as:	Area in (000) ha
1	National Parks	100
2	Game Reserves	780
3	Bird Sanctuaries	137
4	Other Wildlife Areas	260

Note: Marine Areas are not included

6.3.4 Agriculture

Sudan possesses huge agricultural potential and agricultural activities dominate the economy. While more than one third of the country area (about 84 million ha) is considered arable land, only 21% of this area is actually cultivated (FNC, 1995). Agriculture in Sudan is carried out on either irrigated or rainfed systems, as described below.

- **Irrigated farming systems:** About 92% of all irrigated areas are managed by public corporations such as the Gezira and Managil schemes, Girba and Rahad, Blue and White Niles. As such, decision making on management of the irrigated areas is dominated by civil service from different ministries. The present policy trends are going towards decentralization and privatization. The total area irrigated is about (2 million ha) that depends on about 16.8 km^3/year of Nile water.
- **Rainfed farming Systems:** The rainfed farming system area (non-irrigated cultivation under 300 – 400 mm of rainfall) extends to the humid and nearly subtropical conditions in the higher elevations of the southern region. The northern limit represents the latitude at which crop and livestock production will typically succeed. Given current soil nutrient status, crop and forage production is mainly a function of the amount of rainfall and distribution during the growing season. Recent development policy provides contracts for farmers in this sub-sector to allocate 10% of their farm area to shelterbelt and wood lots.
- **Mechanized rainfed farming systems:** This system was introduced in mid-1940s to increase food production. Farm size varies between about 400 and 600 hectares. Typically, farmers use a medium size tractor (65 – 75 Hp) and a wide level disc harrow seeder box. This system was a real improvement over the traditional (Harig) shifting cultivation system which is less practiced now because of population pressures, and the introduction of mechanized farming which covers more than 6 million hectares at present. This system is characterized by intensive clearance of natural vegetation and excessive burning of on-side biomass that contributes significantly to GHG emissions.
- **Traditional rainfed farming systems:** This system is the oldest and most widely used production system in Sudan, constituting a system of mixed farming, where the bulk of the livestock is found, except in the extreme north (rainfall less than 300 mm) where only nomadic livestock herders are found. Under this system, the farm size and cropping patterns are determined by rainfall and soil type. The average holding size ranges between 2 and 5 hectares and the total area under cultivation is estimated at about 7.8 million hectares (including shifting cultivation). Agricultural operations are primarily conducted by family labor with ordinary agricultural tools. In some parts of Sudan, this system is also known as the *harig* system referring to the use of fires in land clearance and burning of agricultural residues, which indicate the contribution of this sub-sector to GHG emissions.

6.3.5 Urban Land Use

Land area occupied by cities and villages is mainly located near the River Nile and its tributaries and in scattered valleys. Recent demographic trends indicate rapid increases in urban areas due to rural-urban migration caused by drought and other environmental factors that have adversely impacted the productive system in rural areas. According to the last population projection, the urban population is expected to grow by an annual rate of 4.4% over the 1995 to 2015 period, which is faster than the overall population growth rate.

6.3.6 Desert and Waste Lands

According to Harrison & Jackson's (1958) classification of major ecological zones of Sudan, the term" natural desert" refers to areas where vegetative cover is absent except along water courses, and average annual rainfall is less than 75 mm. On the other hand, "wastelands" are areas that are either degraded from human activities or vulnerable to desertification.

Despite the severity of the desertification problem, and the various efforts to combat it, statistics on recent trends and geographic extent are very poor. This complicates any effort to determine the actual area affected or vulnerable. However, some ground surveys were carried out during the drought of 1983 indicating that the areas most severely affected lie between latitude 10˚- 18˚ N (i.e., in semi-desert and northern fringe of low rainfall, sandy, savannah zones). This represents most of rangeland areas (Drag, 1994).

According to RPA estimates, degraded areas constitute about 19.5% of total rangeland (about 15,699,000 ha). This area was considered as wasteland area in the land use scenario discussed below.

6.4 Mitigation Analysis

6.4.1 Study area and time Horizon

The study area for conducting the mitigation analysis covers only the area from latitude 10º - 22º North, comprising about 189.4 million hectares. The base year selected for this study is 1995. Projections for baseline and mitigation scenarios were made up to 2025 (planning horizon of 30 years) using the COMAP model. Implementation of mitigation options are assumed to start in the year 2001.

The area below latitude 10º North (Southern States) was excluded at this stage because of the security situation created by the current civil war. In this part of Sudan, forestry (constituting more than 60% of total forest area) and rangeland are dominant land uses that possess significant potential for carbon sequestration projects. But, the information available is neither sufficient nor reliable, and was not covered by the last forest inventory (1998).

6.4.2 Baseline Scenario

6.4.2.1 Assumptions

Since the 1980s, the government adopted a horizontal expansion policy (area increase) in the agricultural sector to meet the successive increase in the population needs and to insure food security. This policy clearly implies the conversion of more forest and rangelands, a trend that has, in fact, been evident since the early 1970s.

The forests in Sudan have also been subjected to continuous clearance for fuel wood and building poles and timber to meet increasing demands for these commodities. Elsiddig et al (1999) estimated the annual rate of forest clearance at 455,000 hectares, which is close to the FAO (1993) estimate for deforestation rate in Sudan (481,700 ha/year). This area is mostly converted to agricultural use. As a percentage of the total cultivated area in Sudan, the annual rate of forest clearance is equal to about 2.6%/yr, which is comparable to the population growth rate as estimated by the statistical authority (population census, 1993). For forests located near urban areas, it is assumed that the annual clearance rate grows at a rate equal to the urban population annual growth rate.

6.4.2.2 Methodology

The Baseline scenario represents expected future changes in land use based on an extension of current trends and the available sectoral plans. Using Elsiddig's (1999) estimate of about 455,000 hectares of forest land cleared annually for agricultural purposes:

- A per capita conversion rate of forest area and rangeland to agriculture for the base year 1995 has been calculated.
- Forest and rangeland area converted to agriculture during the period 1995-2025 has been projected based on the population growth rate estimated for the period (1995-2015) as given by the statistical authority, but for this study the rate of growth has been used up to 2025.
- The area converted to agriculture during (1995 - 2015) was deducted from the three forest categories (>20%, 10% - 20% and <10% crown cover) proportionate to the landuse area of each forest category.
- The same area was then added to irrigated and perennial, mechanized, and tradition rainfed cropland zones, also proportionate to the area of each of these land-use, thus relating expansion of agriculture to population growth over the period 1995 - 2025.
- Expansion of urban area over the same period (1995 - 2025) was projected based on the per capita and the urban population growth estimates.
- The projected expansion in urban areas during the period (1995 - 2025), is assumed to be at the expense of irrigated and traditional cropland areas. Accordingly, this area was deducted from the area under these two categories.

Land use projections in the Baseline Scenario are summarized on Table 6.2.

6.4.3 Afforestation and Rehabilitation Mitigation Scenario

This scenario is based on the afforestation and rehabilitation of wastelands, together with the planting of 10% and 5% of the rainfed and irrigated agricultural land as stated in the NCS (1992-2002), respectively.

6.4.3.1 Assumptions

This scenario expands the biomass stock and hence the carbon stock on available lands. According to the Baseline Scenario, there is expected to be about 15.7 million hectares of wasteland that could be used for this purpose. In addition, the CNS implies that 10% and 5% of the rainfed and irrigated agricultural sectors should be allocated for expansion of forests. On the other hand, demand for forestry products and for animal feed are considered determinant factors for the sustainability of the biomass stock on forests and rangeland.

6.4.3.2 Methodology

The Afforestation and Rehabilitation Scenario represents future changes in land use by taking into account demands for forest products and feed requirements, as follows:

Table 6.2: Baseline Scenario (thousand hectares)

Land Use	Land Type	1995	2000	2005	2010	2015	2020	2025
Forest	>40% crown cover	0	0	0	0	0	0	0
	>20% crown cover	3,200	3,055	2,895	2,718	2,523	2,308	2,070
	10-20% crown cover	4,690	4,473	4,233	3,968	3,675	3,352	2,996
	Subtotal	7,890	7,528	7,128	6,686	6,198	5,660	5,066
Rangeland (<10% crown cover)	Scattered trees & shrubs	44,693	42,768	40,514	38,027	35,280	32,247	28,899
	Grasslands	20,110	19,982	19,969	19,954	19,938	19,920	19,900
	Wastelands	15,699	15,699	15,699	15,699	15,699	15,699	15,699
	Other	0	0	0	0	0	0	0
	Subtotal	80,502	78,449	76,182	73,680	70,917	67,866	64,498
Protected	Wildlife sanctuaries	1,186	1,186	1,186	1,186	1,186	1,186	1,186
	National parks	2,166	2,166	2,166	2,166	2,166	2,166	2,166
	Other	0	0	0	0	0	0	0
	Subtotal	3,352	3,352	3,352	3,352	3,352	3,352	3,352
Irrigated Agriculture	Irrigated and Perennial	2,124	2,437	2,782	3,163	3,583	4,046	4,558
	Current fallow	1,048	1,048	1,048	1,048	1,048	1,048	1,048
	Canals	139	139	139	139	139	139	139
	Subtotal	3,311	3,624	3,969	4,350	4,770	5,233	5,745
Rainfed Agriculture	Mechanized	6,250	7,192	8,232	9,380	10,648	12,047	13,593
	Traditional	7,820	8,974	10,248	11,653	13,204	14,915	16,803
	Shifting	0	0	0	0	0	0	0
	Other	0	0	0	0	0	0	0
	Subtotal	14,070	16,166	18,480	21,033	23,852	26,962	30,396
Other	Urban	30	36	44	54	66	80	97
	Dams and roads	350	350	350	350	350	350	350
	Mines	0	0	0	0	0	0	0
	Subtotal	380	386	394	404	416	430	447
Non-Arable	Desert	79,878	79,878	79,878	79,878	79,878	79,878	79,878
	Grand Total	189,383	189,383	189,383	189,383	189,383	189,381	189,382

Note: A value of zero in all categories other than ">40% crown cover" should be interpreted to mean that there is insufficient detailed and reliable data to justify a non-zero value. However, these are small size categories. No significant land use changes are expected from mitigation options.

- According to the forest product demand study (1994) and the National Forest Inventory (NFI, 1998), there is an annual deficit of about 4,849,112 m^3 due to demand for forest products.
- Assuming an average stocking density of about 8 m^3/ha, based on the average density of the forest types under the category between 10-20% crown cover, the annual deficit can be estimated as equal to an area of about 606,000 hectares of this forest land category.
- If existing declining trends in forest area continue, the total area is expected to decline to about 2,797,000 hectares by the between 1995 and 2001. This reduction in forestland will further increase the gap between the supply and the demand substantially.
- An estimated additional forest area of about 3,403,000 hectares is needed to compensate for this deficit in meeting the demand in forest products.

- The Forestry Outlook Study 2000-2020 (FNC, 2000) projected that household (the major consumer) total wood fuel use will increase from current levels of 14.4 million m^3 to at least 36.9 million m^3, and possibly as much as 39.8 million m^3 in 2020 due to population growth (estimated to be 43.8 million by 2020).
- Local experts expect a reduction in household wood demand due to a shift to fossil fuels made available from domestic oil exploitation activities. Since no estimates are available regarding the extent of this expected fuel shift, it was assumed that the rate of reduction in wood fuel demand from fuel shifting was equivalent to the projected population growth rate.
- Animal feed balances were determined based on forage capacity of rangeland, forest, agricultural by-products & concentrates, and indicate an annual feed deficit of 14.8 tonnes. Using average feed production per hectare for rangelands, this deficit is equivalent to the production of about 14.5 million hectares of rangeland.
- The CNS (1992 - 2002) stated that 10% of the rainfed and 5% of the irrigated agricultural area should be allocated as forestry shelterbelts and woodlots. This will transfer about 3,250,000 hectares from agricultural to forestry use during the period 2000-2025 (or about 130,000 ha/year), thereby partially compensating for the deficit in forest product demand.
- Rangelands and Forests are interrelated land uses, many natural forests are mainly used as grazing area.
- Available wasteland can be utilized to meet the deficit in, the feed requirements, demand for forest products and for further expansion of the biomass stock for the GHG mitigation purposes.
- Taking into consideration the demand of each sector, the team decided to divide the wasteland as follows: 40% for forests, 40% for rangelands (scatter trees and shrubs subcategory), and the balance of 20% for rangeland (grassland subcategory).

Land use projections in the Afforestation and Rehabilitation Scenario are summarized on Table 6.3.

6.4.4 Management Scenario

The second scenario is termed the “Management” Scenario. It is mainly based on protection, and/or rehabilitation of degraded forests and rangelands. It also encompasses land conservation options where good potential exists for carbon sequestration.

The stock density of forest resources in the study area is very poor. The last forest inventory (1998) indicated that stock volume has declined to nearly 50% by 1983. The average standing volume per hectare might be as low as 1.05 cubic meters and rarely exceeds 6.8 m^3. This is attributed to high consumption rates that exceed the annual increment by more than 4 million cubic meters.

According to Elsiddig *et al* (1998), natural forests and woodlands are heavily mined for fuel wood. This is in addition to pressure exerted from various users including mechanized and traditional farming, and overgrazing. Another important factor causing forest degradation is the lack of management and sustainable utilization programs. Despite the start of forest management in Sudan in the 1940s, only about 1.5% of all forest reserves (8 million ha) has been put under proper management. Elsiddig *et al* (1998) concluded that natural forest reserves and natural forests outside the reserves are sustainably mismanaged in spite of forest policies and legislation (i.e., the 1989 Forest Act) that emphasized the need for forest protection, conservation and development.

Table 6.3: Afforestation and Rehabilitation Mitigation Scenario (thousand hectares)

Land Use	Land Type	1995	2000	2005	2010	2015	2020	2025
Forest	>40% crown cover	0	0	0	0	0	0	0
	>20% crown cover	3,200	3,055	3,545	4,018	4,473	4,908	5,320
	10-20% crown cover	4,690	4,473	5,483	6,468	7,425	8,352	9,246
	Subtotal	7,890	7,528	9,028	10,486	11,898	13,260	14,566
Rangeland (<10% crown cover)	Scattered trees & shrubs	44,693	43,255	42,919	42,417	41,733	40,848	39,740
	Grasslands	20,110	19,494	19,449	19,333	19,140	18,859	18,484
	Wastelands	15,699	15,699	12,564	9,429	6,294	3,159	24
	Other	0	0	0	0	0	0	0
	Subtotal	80,502	78,448	74,932	71,179	67,167	62,866	58,248
Protected	Wildlife sanctuaries	1,186	1,186	1,186	1,186	1,186	1,186	1,186
	National parks	2,166	2,166	2,166	2,166	2,166	2,166	2,166
	Other	0	0	0	0	0	0	0
	Subtotal	3,352	3,352	3,352	3,352	3,352	3,352	3,352
Irrigated Agriculture	Irrigated and Perennial	2,124	2,437	2,737	3,073	3,448	3,866	4,333
	Current fallow	1,048	1,048	1,048	1,048	1,048	1,048	1,048
	Canals	139	139	139	139	139	139	139
	Subtotal	3,311	3,624	3,924	4,260	4,635	5,053	5,520
Rainfed Agriculture	Mechanized	6,250	7,192	7,962	8,840	9,838	10,967	12,243
	Traditional	7,820	8,974	9,913	10,983	12,199	13,575	15,128
	Shifting	0	0	0	0	0	0	0
	Other	0	0	0	0	0	0	0
	Subtotal	14,070	16,166	17,875	19,823	22,037	24,542	27,371
Other	Urban	30	36	44	54	66	80	97
	Dams and roads	350	350	350	350	350	350	350
	Mines	0	0	0	0	0	0	0
	Subtotal	380	386	394	404	416	430	447
Non-Arable	Desert	79,878	79,878	79,878	79,878	79,878	79,878	79,878
	Grand Total	189,382	189,382	189,382	189,382	189,382	189,382	189,382

Note: A value of zero in all categories other than ">40% crown cover" should be interpreted to mean that there is insufficient detailed and reliable data to justify a non-zero value. However, these are small size categories. No significant land use changes are expected from mitigation options.

Forest policies emphasize that felling outside forest reserves should be prohibited, and that management should be concentrated inside forest reserves where fellings should be strictly controlled to ensure sustainability. Unfortunately, very few forest reserves have been put under management. As a result of mismanagement and continuous illegal fellings inside and outside forest reserves, the natural forest cover has declined from about 40% of total area in 1958 to about 12% at present. The forest reserves that were fully stocked at the time when reservation processing commenced have become almost completely denuded. Others have experience drastic reductions in stock density despite protection and enforcement measures.

Table 6.4 shows the decline in stocking densities of selected forest reserves as indicated by successive inventories. These forests were fully stocked when they were initially set apart as reserved land.

Table 6.4: Inventory Result of selected Natural Forest Reserves

		Area (ha)		**Stocked area inventory**			**Net Stocked**			**Net Bare Area**
Forest	**Inventory Year**	Total	Stocked	No. of Plots	No. of Stocked Plots	%	Total Area (ha)	Stock density (m^3/ha)	Trees per ha	(ha)
Dalli-Bosi	1990	10,080	5,920	293	171	58	3,434	5.2	132	6,646
Abu Rawag	1989	8,400	4,464	214	164	77	3,421	6.4	240	4,979
Eleraiga	1991	3,835	2,330	157	77	49	1,879	4.2	55	2,056
Saraf Saeeal	1995	15,750	7,875	0	0	0	0	0	50-700	7,875
Sam Sam	1994	25,087	0	0	0	0	0	0	0	25,087

Source: Elsiddig (1998).

However, pilot projects in selected natural forests reserves indicated that rehabilitation and restocking of the forest reserves is successful provided that the forests are put under proper management involving local participation. Elrawashda forest reserve (50,000 ha) is an example of successful protection and rehabilitation activities based on an integrated agroforestry system with local people participation. Annual planting of trees practiced by contracted farmers since 1994 have resulted in stocking densities of 84% - 97% (Table 6.5).

Table 6.5: Tree Stocking for Elrawashda Forest

	1995		**1996**		**1997**		**1998**		**1999**	
Species	N/ha	%	N/ha	%	N/ha	%	N/ha	%	N/ha	%
Talih	1,903	83	1,728	80	1,646	80	1,582	78	1,606	84
Hashab	350	15	336	16	336	16	338	17	240	13
Other	50	2	96	4	82	4	96	5	74	3
Total	**2,303**	**100**	**2,160**	**100**	**2,064**	**100**	**2,016**	**100**	**1,920**	**100**

Source: Osman (1999)
Notes: N=number; Hashab= Acacia Senegal; Talih= Acacia Seyal; Other= Acacia Melifera, Zizyphus spp

Rehabilitation of rangelands was carried out through application of improvement and management techniques such as protection and improved management. Protection of deteriorated range sites was carried out by establishing fenced grazing reserves or allotment reserves in collaboration with local communities. This has resulted in increased carbon sequestration through improved range condition and soil carbon. Le Honero (1972) reported that plant community produce: an average of 4-5 times more forage after 2-5 years of protection form continuous grazing.

Improved management includes:

- **Firelines:** fire burns at an annual average of 20% of the total biomass production of rangelands, therefore establishment of firelines at the end of wet season was carried out to reduce fire hazard. This activity was combined with seed collection; it was conducted by local councils in collaboration of local communities under technical advice provided by RPA.

- **Water development:** it improves both utilization of a viable forage and livestock distribution, however, due to lack of integration, misallocation of water sources occurred.
- **Grazing management system:** these systems have been practiced in very limited rangeland sites. The most commonly practiced system is deferred grazing on improved grasslands. During deferred grazing, the value of benefits reduces to zero. However, it allows better opportunity for plants to regenerate and increase carbon sequestration.
- **Proper utilization:** it is required to ensure that forage production is kept in improved condition. In Sudan, Mohamed (1990) found that 80% utilization is recommended by the end of grazing season.

Although scattered trees and shrubs make considerable contributions to animal feed, especially at the dry season where forage quality and quantity were very low, they have been given little management attention.

Range management exhibited various degrees of success and failure due to absence of clear-cut policies, lack of coordination among natural resources institutions, and absence of legislations.

6.4.4.1 Assumptions

As indicated earlier, the Baseline Scenario assumes that area under the various forest categories are being continuously converted to agricultural land to meet the increasing demand of the growing population. Furthermore, remaining forest reserves and forests outside the reserves continue to be unsustainably utilized, resulting in an increasing deficit in wood product supply. Given current rates of population growth, forests will continue to be converted and reduced in density. Therefore, the forest management techniques assumed in this Management Scenario represent urgent action needed to sustain remaining forest area.

Moreover, due to a deficit in livestock feed balance and a gradual increase of livestock population, there is a need to increase range productivity per unit area through protection and management techniques. The process of forest reservation and conversion of natural forest areas into protected land for wildlife and other purposes will be enhanced by the enforcement of the NCSs decision calling for the protection of 25% of the total country area as forest, rangeland and wildlife.

6.4.4.2 Methodology

The aim of the Management Scenario is to develop forest management plans and improvement of the available ones on existing reserves area (8 million ha). It is assumed that this will be achieved through enrichment planting and adoption of improved silvicultural operations, development of sustainable harvesting programs and efficient logging practices, and through the consideration and direct involvement of relevant stakeholders. The outcome is expected to reduce the deforestation rate, improve the stocking density of the reserved area to above 40% crown cover, and maximize output from these forests areas.

Conversion of the area proposed by the wildlife authorities (1,182,000 ha) into protected area for wildlife purposes will improve the stocking density of this area and sustains its carbon stock. The

Management Scenario represents future changes in land use and takes into account new management practices, as follows:

Eight million hectares of forest reserves are deducted from forest categories between 10%-20% and above 20% crown cover, and added to the forest category above 40% crown cover.

The impacts of improving the management and utilization of forest reserves are expected to relieve some of the pressure on other natural forests and hence their stocking densities are expected to improve. Accordingly, it is assumed that part of the forest with poor stocking density (e.g. 10-20% and < 10% crown cover) will move into higher density categories.

About 1,056,000 hectares from the forest land categories will be converted into protected areas in addition to 100,000 hectares from the desert area, which is planned to become a national park.

Land use projections in the Afforestation and Rehabilitation Scenario are summarized on Table 6.6.

6.5 Analysis of Selected Mitigation Options

The mitigation scenarios should be considered as technical potential scenarios. This is because land use in Sudan is still not stable and many significant changes are expected to take place. In the selection of the different mitigation options special consideration was given to the demand for forest products and the feed requirements of the national herd, this is because forestry and rangeland are closely interrelated land uses. However, option selection also considered the integration of forestry into agriculture, as it is called for by present policies. Also, it is assumed that the benefits of these options extend well beyond carbon sequestration.

6.5.1 Forestry Options

Given the structure of demand for biomass, 40% of available wasteland (about 6,250,000 ha) in the Baseline Scenario was assumed to be used for forestry purposes, after satisfying grazing needs. Due to poor condition of these areas it is assumed that rehabilitation will result in relatively low density forests of Acacias as indicated in Table 6.7.

Conversion of biomass (m^3) to dry matter (tonnes) is made by adjusting the volume by an average wood density of (0.72) and an average wet/dry wood ratio of 16% (FNC, 1994).

In the selected forestry options, cultivation of certain crops (sorghum and sesame) by farmers or forest workers is assumed to take place in the first three years (depending on the canopy closure). Cultivation of crops under the newly planted trees is an old practice in Sudan (e.g. Tongia system). Grazing is also one of the common practices in Acacia forests; i.e., when newly planted trees are 5 years old animals are allowed to graze the under story vegetation. Data on costs and benefits of afforestation options are based on government records and market prices. Table 6.8 shows data used in cost/benefit calculations.

The implementation of forestry options is expected to offset the deficit in forestry products. The direct involvement of local communities and the consideration of the needs of all relevant stakeholders are considered by the team as essential for the successful implementation of these options. To meet farmer needs, crop cultivation will be allowed between the trees for the first three years. Forestry options are summarized in Table 6.9.

Table 6.6: Management Mitigation Scenario (thousand hectares)

Land Use	Land Type	1995	2000	2005	2010	2015	2020	2025
Forest	>40% crown cover	0	0	0	2,000	4,000	6,000	8,000
	>20% crown cover	3,200	3,055	3,539	3,172	2,787	2,382	1,954

	10-20% crown cover	4,690	4,473	5,473	5,188	4,875	4,532	4,156
	Subtotal	7,890	7,528	9,012	10,360	11,662	12,914	14,110
Rangeland (<10% crown cover)	Scattered trees & shrubs	44,693	43,255	42,919	42,267	41,433	40,398	39,140
	Grasslands	20,110	19,494	19,449	19,333	19,140	18,859	18,484
	Wastelands	15,699	15,699	12,564	9,429	6,294	3,159	24
	Other	0	0	0	0	0	0	0
	Subtotal	80,502	78,448	74,932	71,029	66,867	62,416	57,648
Protected	Wildlife sanctuaries	1,186	1,186	1,202	1,202	1,202	1,202	1,202
	National parks	2,166	2,166	2,266	2,526	2,786	3,046	3,306
	Other	0	0	0	0	0	0	0
	Subtotal	3,352	3,352	3,468	3,728	3,988	4,248	4,508
Irrigated Agriculture	Irrigated and Perennial	2,124	2,437	2,737	3,073	3,448	3,866	4,333
	Current fallow	1,048	1,048	1,048	1,048	1,048	1,048	1,048
	Canals	139	139	139	139	139	139	139
	Subtotal	3,311	3,624	3,924	4,260	4,635	5,053	5,520
Rainfed Agriculture	Mechanized	6,250	7,192	7,962	8,840	9,838	10,967	12,243
	Traditional	7,820	8,974	9,913	10,983	12,199	13,575	15,128
	Shifting	0	0	0	0	0	0	0
	Other	0	0	0	0	0	0	0
	Subtotal	14,070	16,166	17,875	19,823	22,037	24,542	27,371
Other	Urban	30	36	44	54	66	80	97
	Dams and roads	350	350	350	350	350	350	350
	Mines	0	0	0	0	0	0	0
	Subtotal	380	386	394	404	416	430	447
Non-Arable	Desert	79,878	79,878	79,878	79,878	79,878	79,878	79,878
	Grand Total	189,383	189,382	189,483	189,482	189,483	189,481	189,482

Note: A value of zero in all categories other than ">40% crown cover" should be interpreted to mean that there is insufficient detailed and reliable data to justify a non-zero value. However, these are small size categories. No significant land use changes are expected from mitigation options.

Table 6.7: Tree species used in rehabilitation of Wastelands

		Mean Annual Increment (m^3/ha)		**Density (m^3/ha)**	
Species	**Rotational age (years)**	Waste-land	Agricultural land	Waste	Agricultural land
Hashab	20	3.0	3.8	60	76
Talih	15	3.8	5.0	57	75
Mix Acacia 60% Hashab	19	4.3	4.3	59	77
Mix Acacia 60% Talih	17	3.5	4.5	60	77
Eucalyptus	20	0	21.0	0	420

Table 6.8: Economic input assumptions - forestry options

	Costs		Benefits		Harvest	
Activity	(US$/ha)	Product	Units	US$/unit	(units/ha)	Remarks

Afforestation (Acacias spp.)	30	Fuel wood	m^3	4.7	refer to Table 6.7	Gum Arabic price used is the local price set by the national company
		Gum arabic	Tons	218.0	0.1	
Cultivation	25	Sorghum Sesame	Sack Sack	9.7 46.0	7.2 4.8	Data obtained from the Agric. Inform. & Statist. Department
Grazing	Not available	Fodder	Hectare	2	0.2	Grazing is practice d for 10-15 years (till harvesting). This value is Rent/ha/season

Table 6.9: Afforestation and Rehabilitation of Wasteland – Forestry Options

Species	No. Of Options	Discount Rate	Total Afforested Area (000 ha)	Rotational Age	Remarks
Hashab	1	10%	6,250	20	
	2		6,250	20	
	3		6,250	20	
Mix Acacias (60% Hashab 30% Talih 10% others)	1	10%	6,250	19	For Mix acacias, an average rotation is used based on the percentage of the species used
	2		6,250	19	
	3		6,250	19	
Mix Acacias (60% Talih 30% Hashab 10% others)	1	10%	6,250	17	
	2		6,250	17	
	3		6,250	17	

6.5.2 Rangeland Options

Rangeland is the second category of options for forest land. It is divided into two subcategories, scattered trees and shrubs and grasslands.

The estimated area for rehabilitation of scattered trees and shrubs is 6,250,000 hectares (40% of the wasteland in the land use scenario). Rehabilitation practice and tree planting (mainly fodder trees) and reseeding of associated grass is proposed. Benefits obtained will contribute to enhanced browsing and production of non-timber products

Using a discount rate of 10%, typically used by local agriculture banks for long-term investment, the following options are suggested (Table 6.10).

Table 6.10: Afforestation and Rehabilitation of Wasteland – Scattered Trees and Shrubs Options

			Cost US$/ha				Benefit US$/ha		Biomass Density tonne/ha	
				Mitigation (M)						
Option	Area (000 ha)	Age	B	Initial	Main	Monit	B	M	B	M
90% leguminous spp 10% perennial grasses	6,250	20	0	40	5	2.5	13	96	2	21
50% leguminous spp. 30% others, 20% perennial grasses	6,250	20	0	40	5	2.5	13	96	2	21

Notes:
B=Base Case; M=Mitgation Case
Leguminous spp : Acacias spp. (e.g. albida) + Phiostigma reticulatium
Associated grasses Balanities agyptiaca, Ziziphus spaina Christi &other associated spp. of browsing value.

Mitigation options for grassland (Table 6.11) will depend mainly on community based rehabilitation on 3,139,300 hectares (20% of wasteland) according to present status and strategies of pastoral sector development the area subdivided as follows:

50% open rangeland = 1,569,900 ha
35% GRAZING RESERVES AND ALLOTMENT = 1,098,930 HA
15% ranches = 470,970 ha
Total = 3,139,300 ha

Table 6.11: Afforestation and Rehabilitation of Wasteland – Grassland Options

			Cost US$/ha				Benefit US$/ha		Biomass Density[2] tonne/ha	
				Mitigation (M)						
Alternative mitigation Option	Area (000 ha)	Age[1]	B	Start	Maint.	Monit	B	M	B	M
Open rangeland 86% reseeding grass mixture 10% leguminous trees 5% cultivation	1,570	20	0	28.9	5	2.5	12.4	43.7	0.2	1.1
Grazing reserves & allotment 90% reseeding grass mixture 10% trees & shrubs	1,099	30	0	47.7	5.6	2.5	12.4	69.4	0.2	1.6
Ranching 70% reseeding 30% cultivation	471	25	0	47.7	5.7	2.2	12.4	79.4	0.2	1.6

Notes:
B=Base Case; M=Mitgation Case
[1] *Rotation ages in the case of rangeland indicate the reseeding and rehabilitation intervals.*
In Sudan, 20 -25 years rotation is the practiced, which is also the average age for the tree species used.
[2] *Biomass density here include both grassy (1.4) and woody vegetation (0.2)*

6.5.3 Other Options

There are 2 other options that represent current policy initiatives at various stages of implementation. The afforestation of 5% of irrigated agricultural areas is one such initiative that is being implemented rather slowly. Because of the high potential, the main species selected for analysis is the Eucalyptus spp, under three different discount rates (5%, 10%, and 15%) (Table 6.12). The main products expected from this afforested area are building materials (poles).

Table 6.12: Afforestation and Rehabilitation Options - Irrigated Agricultural Area

Species	**Discount rate**	**Total afforested area (000 ha)**	**Rotational age**
Eucalyptus spp.	10%	5% of the irrigated agricultural area	20 20 20

The afforestation of 10% of the rainfed agricultural areas is another option. This is also related to the existing policy decision that is also implemented slowly. Different species or a combination of species could be analyzed here using the three discount rates. Because of the relatively high potential of this area, it is expected to be able to produce denser forest with >20% crown cover and make significant contributions to the various needs for forestry products. Possible options are shown in table 6.13.

Table 6.13: Afforestation and Rehabilitation Options - Rainfed Agricultural Area

Species	No. of options	Total afforested area in 000 ha	Rotational age	Remarks
Mix Acacias (60% Hashab; 30% Talih; 10% other)	1	10% of the rainfed agricultural area	19	For Mix acacias, an average rotation is used, based on the percentages of the species used
	2		19	
	3		19	
Mix Acacias (60% Talih; 30% Hashab; 10% other)	1	10% of the rainfed agricultural area	17	
	2		17	
	3		17	
Hashab	1	10% of the rainfed agricultural area	20	
	2		20	
	3		20	
Talih	1	10% of the rainfed agricultural area	15	
	2		15	
	3		15	

Notes: Hashab= Acacia Senegal; Talih= Acacia Seyal; Other= mix of Acacias and other associated species.

6.5.4 Management Options

Improving forest and range management in Sudan is considered an urgent need for conserving remaining forest and range areas. Serious management steps will need to be undertaken to arrest the unsustainable use of forest resources. Options may include revision and updating of current policies, development of sustainable management plans with adequate considerations for relevant stakeholders. Regarding the present situation of the resources, management prescription should include rehabilitation (e.g. enrichment planting), protection and a range of conservational measures.

For the mitigation analysis, it was assumed that the total area of reserves (8 million ha) will be brought under sustainable management and its stocking density will be improved substantially, reaching a >40% crown cover density category. In addition, protected areas are expected to increase from 3,352,000 hectares in 1995 to 4,508,000 hectares in 2025 due to the implementation of the proposed plans. This may also increase the stocking density of this area to >40% crown cover and carbon sequestered will have greater longevity potential. Using the same discount rate (i.e., 10%), the analysis considered the following options (Table 6.14).

Table 6.14: Management Options - Forests

Options	Area (000 ha)	Stocking density (% of crown cover) Baseline Case	Mitigation Case	Discount rate
Improvement of forest protection and management	3,200 4,800	> 20 10 - 20	> 40 > 40	10%
Conversion of natural forests into protected land for wildlife purposes	166 290 600	> 20 10 - 20 < 10	> 40 > 40 > 40	10%

Management options for achieving rangeland protection are based on the combination of an ecological approach and community participation. Since range ecosystems are difficult to protect under open grazing systems, demonstration of range resource protection must be coupled with strong extension programs. The most corrective management measures for range protection are described below and summarized on Table 6.15.

- **Prescription burning:** this activity is carried out mainly in the rainfall savanna and southern part of semi-desert zones. However, wet season grazing areas along this belt are the most vulnerable areas to seasonal fire hazards. Annual estimated fire line length in this area varies between 15,000-25,000 linear km depending on the amount of rainfall and consequent vegetation density. It is establishment protects average of 30% of biomass production in an area of about 40,723,210 hectares. This practice increases carbon emissions to the atmosphere and may temporarily destroy resources but it has long-term productivity benefits.
- **Application of range management systems in existing grazing perimeters (12,000 ha):** Lack of management and proper utilization has led to a deterioration of standing stocks to about 30% of their potential after only 7 years of heavy grazing (Currte, 1967). In West Sudan, 80% of utilization was recommended by the end of grazing season (Mohammed, 1990).
- **Protection and management of Baja grazing region:** The area, about 714,288 hectares, will be protected and managed through the development of 6 water wells. Due to the seasonality of existing water sources, this will change animal distribution, which will affect the amount of carbon sequestered through uptake of soil carbon, increase in woody vegetation, reduction in soil erosion, and avoided emissions associated with overgrazing. The establishment of 1,000 linear km of fire lines (prescribed burning) will save 30% of the total biomass and will benefit plant quality.

6.6 Results

The analysis of the various mitigation options under each scenario was conducted using the COMAP model. Results are shown on Table 6.16 for selected options. The cumulative values of carbon sequestration obtained from the COMAP model runs indicate that the afforestation of the available irrigated agricultural land with Eucalyptus spp. option shows the largest value of incremental carbon sequestered. Improving forest management ranks second while the afforestation of rainfed, and afforestation and rehabilitation of wasteland options show (more or less) the same level of incremental carbon sequestered.

Table 6.15: Management Options - Rangelands

			Cost US$/ha				Benefit US$/ha		Biomass Density (tonne/ha)	
				Mitigation (M)						
Alternative mitigation Option	Area (000 ha)	Age	B	Start	Maint.	Monit	B	M	B	M
Open rangeland 86% reseeding grass mixture 10% leguminous trees 5% cultivation	12,216,963	20	0.2	0.6	0.0	0.0	0.0	37.3	0	0.6
Grazing reserves & allotment 90% reseeding grass mixture 10% trees & shrubs	12,000	30	0.2	3.2	0.4	0.0	52.0	59.5	0.8	1.2
Ranching 70% reseeding 30% cultivation	714,286	25	0.2	3.7	0.5	0.0	30.4	43.4	0.5	0.7

Table 6.16: Carbon sequestration potential for selected Forestry and Rangeland mitigation options

				Carbon pool (million tC)		
Mitigation Option	Land Type	Mitigation Measure	Land Area (000 ha)	Baseline Scenario	Mitigation Scenario	Incremental carbon sequestered
Forestry	Wasteland	Hashab	6,250	37.5	284.7	247
		Mixed Acacia (60%.Talih)	6,250	37.5	254.9	217
		Mixed Acacia (60%.Hashab)	6,250	37.5	280.2	243
		Rangeland: scattered trees & shrubs	6,250	37.5	287.1	250
		Range grassland: Ranching	471	2.8	23.8	21
		Range grassland: Open range	1,570	9.4	62.0	53
		Range grassland: Grazing reserves	1,099	6.6	66.2	60
	Rainfed	Talih	3,950	160.0	296.0	136
		Hashab	3,950	160.0	326.8	167
		Mixed Acacia (60%.Talih)	3,950	160.0	304.0	144
		Mixed Acacia (60% Hashab)	3,950	160.0	315.0	155
	Irrigated	Eucalyptus spp	296	18.0	101.9	84
Management	Forested	Above 20% Crown cover	3,200	102.4	321.5	311
		Application Mgt. System	12	0.5	0.6	0
		Baga grazing reserve	714	28.8	35.1	6

In Sudan, almost all the mitigation options examined have very attractive benefit-cost ratios compared to many other developing countries. All have very low initial costs and costs per ton of carbon sequestered, on a present value basis. This is summarized in tables 6.17 and 6.18.

Table 6.17: Cost-effectiveness indicators of conserving carbon

				Initial Cost		Present Value of Costs	
Mitigation Option	Land Type	Mitigation Measure	Land Area (000 ha)	US$/tC	US$/ha	US$/tC	US$/ha
Forestry	Wasteland	Hashab	6,250	0.6	23	1.11	44
		Mixed Acacia (60%.Talih)	6,250	0.7	23	1.26	44
		Mixed Acacia (60%.Hashab)	6,250	0.6	23	1.13	44
		Rangeland: scattered trees & shrubs	6,250	0.2	9	0.68	27
		Range grassland: Ranching	471	0.4	16	0.00	0
		Range grassland: Open range	1,570	0.3	11	1.23	41
		Range grassland: Grazing reserves	1,099	0.3	14	0.73	40
	Rainfed	Talih	3,950	0.7	23	7.43	256
		Hashab	3,950	0.5	23	6.06	256
		Mixed Acacia (60%.Talih)	3,950	0.6	23	7.01	256
		Mixed Acacia (60% Hashab)	3,950	0.6	23	7.01	256
	Irrigated	Eucalyptus spp	296	0.2	50	0.91	259
Management	Forested	Above 20% Crown cover	3,200	0.1	6	1.19	116
		Application Mgt. System	12	0.4	3	6.10	54
		Baga grazing reserve	714	0.4	4	7.37	65

Note: 10% Discount Rate used

Table 6.18: Cost of incremental carbon uptake by the different Mitigation options

				Incremental Carbon Sequestered		Costs		
Mitigation Option	Land Type	Mitigation Measure	Land Area (000 ha)	(million tC)	(million tCO_2)	Initial Cost (US$/tC)	Present Value (US$/$tCO_2$)	Total (million PV$)
Forestry	Wasteland	Hashab	6,250	247.2	904.7	0.16	904.7	148.3
		Mixed Acacia (60%.Talih)	6,250	217.4	795.5	0.19	795.5	152.2
		Mixed Acacia (60%.Hashab)	6,250	242.7	888.4	0.16	888.4	14.6
		Rangeland: scattered trees & shrubs	6,250	249.6	913.6	0.05	913.6	49.9
		Range grassland: Ranching	471	21.0	76.9	0.11	76.9	8.4
		Range grassland: Open range	1,570	52.6	192.5	0.08	192.5	15.8
		Range grassland: Grazing reserves	1,099	59.6	218.0	0.08	218.0	17.9
	Rainfed	Talih	3,950	136.0	497.8	0.19	497.8	95.2
		Hashab	3,950	166.9	610.7	0.14	610.7	83.4
		Mixed Acacia (60%.Talih)	3,950	144.0	527.0	0.16	527.0	86.4
		Mixed Acacia (60% Hashab)	3,950	155.1	567.5	0.14	567.5	93.0
	Irrigated	Eucalyptus spp	296	83.9	307.0	0.05	307.0	16.8
Management	Forested	Above 20% Crown cover	3,200	22.5	82.5	0.004	0	0.1
		Application Mgt. System	12	0.1	0.3	0.363	0.1	0.0
		Baga grazing reserve	714	6.3	23.0	0.42	0.11	2.6

Note: 10% Discount Rate used

Table 6.19 summarizes the potential cost and benefits associated with implementation of these mitigation options. All options have relatively high NPV of benefits, indicates that these options are cost effective.

Table 6.19: Summary of Carbon Sequestration Potential and cost effectiveness of Forestry and Management Mitigation Options

				Initial cost		Present value of costs		NPV of Benefits	
Mitigation Option	Land Type	Mitigation Measure	Incremental Carbon Sequestered (000t/ha)	US$/tC	US$/ha	US$/tC	US$/ha	US$/tC	US$/ha
Forestry	Wasteland	Hashab	39.6	0.6	23	1.11	44	1.59	63
		Mixed Acacia (60%.Talih)	34.8	0.7	23	1.26	44	1.42	49
		Mixed Acacia (60%.Hashab)	38.8	0.6	23	1.13	44	1.40	54
		Rangeland: scattered trees & shrubs	39.9	0.2	9	0.68	27	2.94	118
		Range grassland: Ranching	44.6	0.4	16	0.00	0	-0.85	-38
		Range grassland: Open range	33.5	0.3	11	1.23	41	2.27	76
		Range grassland: Grazing reserves	54.2	0.3	14	0.73	40	2.30	125
	Rainfed	Talih	34.4	0.7	23	7.43	256	3.74	129
		Hashab	42.2	0.5	23	6.06	256	3.21	135
		Mixed Acacia (60%.Talih)	36.5	0.6	23	7.01	256	3.56	130
		Mixed Acacia (60% Hashab)	39.3	0.6	23	6.52	256	3.35	131
	Irrigated	Eucalyptus spp	283.6	0.2	50	0.91	259	4.60	1,305
Management	Forested	Above 20% Crown cover	70.4	0.1	6	1.19	116	0.17	17
		Application Mgt. System	8.8	0.4	3	6.10	54	1.82	16
		Baga grazing reserve	8.8	0.4	4	7.37	65	5.39	48

If implemented by the government, these options are expected to have substantial environmental and socio-economic benefits. Environmental benefits include expanding vegetation cover. For example, the afforestation and rehabilitation of wasteland can be expected to restore degraded lands and contribute to arresting the encroachment of the desert. Management options can be expected to increase stock density of forests and rangelands, improve utilization of forests and rangelands resources, enhance the productive and ecological functions, and increase the resilience of the forest and rangeland ecosystems. These effects in turn may lead to further benefits on biodiversity conservation, watershed protection, and to 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. In addition potential carbon credits obtained from LUCF activities may provide opportunities for finance and joint investments.

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