Baseline and Climate Change Scenarios for Ethiopia

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Abstract
This study examines baseline and climate change scenarios. Key environmental problems in Ethiopia are soil erosion and degradation, deforestation, desertification and rangeland degradation. On the average, about 5-6% of natural/closed forest is depleted per year. MOA (1989) estimated that about one billion tones of soil is lost annually. Also about 61% of dryland in the country is prone to desertification hazard. Ethiopian population growth rate (2.92% per year) is one of the highest in Sub-Saharan Africa. Projections indicate that by 2030 the current growth rate would decrease to 1.85%. Official estimates show that presently the economy grows at 5-6% per year. However, the unchecked population growth rate added with environmental problems would pressurize the economy. Therefore, the country’s vulnerability would increase even without climate change. Baseline climate has been developed using 1961-90 temperature and rainfall data. Rainfall variability study has been accomplished by computing averages, standard deviation and moving averages and by identifying extreme wet and drought years in the period of record. In the case of temperature, variability is studied in comparison with the average of the base period. Climate change scenarios were obtained using Global Circulation Models (GCMs) and incremental scenarios. Validation of GCMs was done on monthly and seasonal basis. Among the range of models, models that better estimate the current climate and selected were Geophysical Fluid Dynamics Laboratory’s equilibrium and transient models and Canadian Climate Centre model. Scenarios from equilibrium GCM were prepared by combining observed data with (2xCO2/1xCO2) in case of rainfall and with (2xCO2/1xCO2) in case of temperature. Scenarios from the transient model were obtained by combining model outputs of decadal averages with respective temperature and rainfall observed data. Incremental scenarios were developed by assuming 2 and 4°C increase over the mean for temperature and by adding -20%, -10%, 0, 10%, 20% change to observed rainfall. Models indicated that future temperatures would increase by 0.8 - 3.3°C in Kiremt, 0.5 - 3.4°C in Belg and 0.9 - 3°C in Bega seasons. According to projections, major parts of the country would experience decrease of rainfall for Kiremt. A general decrease of rainfall for Belg was estimated while an increase is projected for the Bega seasons.

Key words: Ethiopia, baseline scenario, climate change scenario, GCM

I. INTRODUCTION
Ethiopia’s economy is mainly based on rain-fed agriculture, which is prone to vagaries of weather and climate. Studies have shown that Ethiopia has been affected by frequent droughts, particularly since the 1950s (e.g. Workineh, 1987). Droughts in the mid-1960s, early 1970s and the 1980s were commonly observed. Of particular are recent droughts in 1972/73 and 1984, the effects of which were aggravated by the political instabilities. These droughts over the country have attracted considerable attention worldwide. Also the country faces environmental problems such as soil erosion and degradation, deforestation, desertification and rangeland degradation. However, as an agricultural country, we do not know whether such environmental problems and/or vagaries of weather and climate would be more frequent as signatures of the changing climate or not. Therefore, it is important for the country to involve itself in climate change studies and vulnerability and adaptation assessments to climate change.

Ethiopia has participated in the U.S. Country Studies Program (USCSP) and conducted vulnerability and adaptation assessment in agriculture, water resources, forestry and rangeland sectors between 1994 and 1997. Hence, work in these economic sectors requires the development of baseline and climate change scenarios for them to serve as inputs.

Scenarios are defined as "plausible conditions that may illustrate future events". They illustrate the effect of a wide range of economic, demographic and policy assumptions. They may be controversial because they reflect different views about future changes and, thus, the use of a number of scenarios could be helpful to

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identify sensitivities to climate change (Smith et al., 1998; Strezepek and Smith, 1995; Houghten et al., 1990). Hence, scenarios can be developed for baseline and future climate.

Baseline scenarios estimate how the world would change without climate change. Climate change scenarios are defined as "physically plausible set of changes in meteorological variables, consistent with generally accepted projections of temperature for an effective doubling of CO₂" (Venir and Hulme, 1994; Houghten et al., 1990; U.S. Country Studies Management Team (USCSMT), 1994; Smith et al., 1998).

Studies show that due to emissions resulting from industrial sources including land use changes and conversion of forests the atmospheric concentration of greenhouse gases (CO₂, CH₄, N₂O, etc.) has been increasing since particularly the pre-industrial times (e.g. Houghten et al., 1996; Mitchell et al., 1990). The impact of this would be manifested in the altered the climate of the globe (e.g. Houghten et al., 1996; Watson et al, 1992).

Although we can not conclusively say that the increase of green house gases concentration alone will increase global temperature, there are evidences that this increase will enhance green house effect (Houghten et al., 1990). The General Circulation Models (GCMs) which are based on the laws of physics has simulated this warming (e.g. Houghten et al, 1990). Though there are uncertainties in climate predictions with regard to direction, timing, variability and extreme events, particularly at a regional scale, the GCMs provide a powerful facility to study climate and climate change (e.g. Gates et al, 1990; Santer et al., 1990; Smith and Tiplak, 1989). And due to the uncertainties, future climate can not be accurately predicted, but future climate can be studied by using scenarios.

The sensitivity studies of climate change focus on climate change caused by radiative forcing agents such as doubling of CO₂ in the atmosphere (Shine et al. 1990). For this, thus, GCMs are selected (Smith et al. 1998; Strezepek and Smith, 1995; Houghten et al. 1990, 1996; Santer et al. 1990). Scenarios developed from models were all checked for consistency and are within the current scientific consensus, that is whether future changes are within the projections of the Intergovernmental Panel on Climate Change (IPCC). IPCC (Houghten et al., 1996) concluded that global average warming lies between 1.5°C and 4.5°C with a "best" guess of 2.0°C by 2100.

This study, therefore, aims at developing (a) baseline scenarios for non-climate change situations and (b) climate change scenarios. Discussion on baseline scenarios is provided in Section II. This includes environment, institutional and socio-economic scenarios. Due to unavailability of data and information, baseline for pollution level has not been done. Environment and institutional scenarios are developed based on data and information from national projects in ministries. Baseline climate data has been organized for temperature and rainfall. Climate change scenarios developed using GCMs and incremental changes are presented in Section III.

II. BASELINE SCENARIOS FOR ETHIOPIA

The objective of formulating baseline scenarios is primarily to make impact assessments. Impact assessments are estimated out of environmental and socio-economic conditions expected to occur over a period of analysis between non-climate and climate change situations (Smith and Pitts, 1997). As environmental and socio-economic conditions are not static, their effects have to be examined by developing a baseline that describe current climatological, environmental and socio-economic conditions. Then the impact assessment community will be able to project environmental and socio-economic conditions in the absence of climate change. The baseline conditions could, thus, be compared, after impact projections, with environmental and socio-economic conditions under climate change. Therefore, the development of baseline representing current and projected conditions in the absence of climate change is of vital importance for the assessment studies (Houghten et al., 1990; Carter et al., 1990; USCSMT, 1994; Hulme et al., 1995).
2.1. Baseline Environmental Scenarios

Changes in environmental conditions could affect the sensitivity of sectors to climate change. Environmental problems in Ethiopia include desertification, soil degradation, deforestation and rangeland degradation.

2.1.1 Deforestation, soil degradation and land-use changes

Agricultural activity and human settlement in Ethiopia are said to start several thousand years ago (Solomon and references therein, 1994; Zerihun, 1988) and it can be inferred that human interference with environment began as soon as this early history. In Ethiopia agriculture is the major economy of the country (about 45% of GDP; Central Statistics Authority (CSA), 1999a). About 60% of the export earnings is also from agriculture (CSA, 1999a). Agriculture is of subsistence type and the practice has been centuries old.

Forest has a profound influence on climate and soil and it has a great role in carbon storage. Thus, the loss of carbon due to forest clearance contributes to the enhancement of greenhouse gases in the atmosphere. Forestry is an important economic sector in Ethiopia and it accounts for about 6.3% of GDP (CSA, 1999a). According to the Ethiopian Forestry Action Program (EFAP) report (MNRDEP, 1994), it is believed that forest cover towards the beginnings of this Century was about 38% of the area of the country. The same report indicates that natural forests in 1989 are reduced to about 2.7 million hectares (2.5%) of the total area. It has been estimated that the annual loss of closed/natural forests range between 150,000 to 200,000 hectares (5.6-7.4% area; MNRDEP, 1994). The need for fuel wood, construction, grazing land and conversion to other forms of land use mainly cause deforestation in the country. The report also estimates the loss of forest in monetary forms. The value of forest depletion in 1990 alone is estimated at about Birr 138 million or some 25% of the potential forestry GDP. It has also been reported that if the current trend of deforestation continues, area covered by high forests in 2010 will be reduced to standing trees here and there, mainly in inaccessible areas of the country (EFAP, 1994). Therefore, the rate of deforestation in Ethiopia has been very high.

Changes in land use could also influence climate and environment. The absence of appropriate land use policy and awareness strategy will result, among others, in soil degradation and reduction of yield. According to the report on land utilization released by the Ministry of Agriculture (MOA, 1993), cultivated land comprises of about 14.8%, grazing land about 51%, and forests including bush and shrub land covers about 11%. In Ethiopia too much soil has been eroded several thousand years ago partly due to inappropriate land use system and as a result of backward system of farming. The Ethiopian Highland Reclamation Study at the Ministry of Agriculture (Wright, 1984) estimates that about 52% of the highland areas are under severe and moderately accelerated erosion. Similarly, a National Conservation Strategy Project at the Ministry of Agriculture (MOA, 1989) estimated that one billion tones of soil are lost annually and 12 million hectares of agricultural land has been severely degraded. Barber (1984) estimates that if soil degradation is allowed to continue at the current rate, over 7 million hectares would become unsuitable for farming in two decades time. Due to soil degradation, Hurni (1988) estimated that the productive capacity of soils would decline at a rate of 2-3% annually. Therefore, with the growth in population (about 2.9% per year), the energy demand will increase, the need for additional crop lands will grow and deforestation and soil degradation will increase even without climate change.

2.1.2 Desertification and ecosystem changes

The United Nations Convention to Combat Desertification (UNCCD, 1992) defines desertification as “land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities”. Various sources (e.g. Environmental Protection Authority of Ethiopia

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* Birr is the local currency, 1USD= 8.0 Birr.
(EPA), 1998) indicate that arid, semiarid and dry subhumid areas account for about 70% of the total land mass of the country whereas about 61% of the total land area is prone to desertification. The problem of desert encroachment will greatly affect Ethiopia. Plant species, wild life and ecosystem will be adversely affected by desertification. Humans will also be affected in different ways.

As per the requirements of the ongoing negotiation at UNCCD, a National Action Plan to Combat Desertification has been formulated (EPA, 1998). The objectives of the Action Plan is to identify and promote policies and short, medium and long-term strategies required to supplement the existing sustainable development framework focusing on combating desertification. However, there would be a time gap between the effective implementation to prevent further desertification or curb the situation and recovery and thus, the problem of desert encroachment would continue even without climate change.

2.2. Baseline Institutional Scenarios

As explained above wide spread degradation of natural resources and the environment are key problems for Ethiopia. To mitigate these problems, measures are under consideration and various policies and laws are in place. The Environmental Policy of Ethiopia (EPA, 1997a) indicates that environmental sustainability is recognized in policies and strategies as a key prerequisite. In line with this an institution in charge of environmental issues at the federal level, Environmental Protection Authority (EPA), is established. The EPA mainly assumes regulatory role and coordinates various activities within line ministries, agencies and non-governmental institutions. To promote sustainable socio-economic development through sound management and rational use of natural resources and the environment, Conservation Strategy of Ethiopia (CSE) has been formulated (EPA, 1997b). The CSE encompasses a number of sectoral and cross-sectoral environmental policies and seeks to integrate into a coherent framework plan, policies and investment related to environmental sustainability. The CSE stresses on community participation and is firmly placed on both bottom up and top down approaches. The Environmental Policy of Ethiopia also includes policy implementation issues like institutional coordination, legislative framework and monitoring, evaluation and policy review provisions.

It is assumed that the present institutions and environmental legislation and policy options in place will be strengthened. Currently measures are being considered to reduce the problem through conservation and sustainable development plans, environmental legislation and other incentive-oriented activities. However, environmental problems will continue in the future before restrictive measures and plans will be fully effective. Therefore, ecosystem changes, i.e., slower natural replacement rate, coupled with the rate of desertification could increase the country’s vulnerability.

2.3. Baseline Socio-Economic Scenarios

Changes in population and GDP could also affect the sensitivity of sectors to climate change. In Ethiopia, the Population and Housing Census was conducted in 1994 by the Office of Population and Housing Census Commission, Central Statistics Authority (CSA, 1999b). The population density is estimated at 47 persons per km². According to the Census results, under a medium variant scenario (i.e., assumption based on the total fertility rate to reduce to approximately 4.0 by 2015 and by 2020), the population of Ethiopia for 1999 is estimated at 61.7 million. By the year 2030, population will increase to 129.1 million. On the average, annual population growth rate is estimated to reduce from the current 2.92% to 1.85% within the projection period (between 2025 and 2030). According to the projections, the present population will double by the year 2037. The Census also showed that the country’s population is rural based. The 1994 estimate show that about 86% of the population resides in rural areas. The rural population grows at the rate of 2.57% per annum while the urban population grows at 4.1% between 2000 to 2005. Urban and rural populations are projected to grow by 3.35% and 1.41%, respectively, between 2025 and 2030. By 2030 urban population would be 22.2% of the total. Life expectancy at birth is estimated at 50.7 years. The structure of the
population reflects a high dependency ratio of 48.6% (i.e., part of the population in the age groups 0-14 and >65 years which are economically inactive).

The country’s economy is mainly based on agriculture. Agriculture and allied activities share about 45% of the GDP while industry takes about 11%. The services sector comprises of about 44% of the GDP (CSA, 1999a; NBE, 1999). The annual growth rate of real GDP (at 1980/81 prices) was estimated at 1.6% for 1994/95, 5.2% for 1995/96, 12.7% for 1996/97 and 6.3% for 1997/98 (CSA, 1999a). The real GDP per capita for 1998/99 is estimated at 121 USD (NBE, 1999). Therefore, though the economy showed some improvement in recent years, the real GDP growth is far behind the rate of population growth. Given the high population growth rate, the overall development programmes would be under pressure. Thus, unless measures are taken to check the population growth rate, the country’s vulnerability could increase tremendously even without climate change.

2.4 Baseline Climate

Reference period chosen to develop baseline climate for Ethiopia is 1961-1990. According to Carter et al. (1992), although this period includes the global warming decade of the 1980s (Jones et al., 1994), there are some merits for choosing the period. First, the baseline coincides with the World Meteorological Organization’s (WMO’s) latest 30-years climatic average and the end of which also coincides with the start of the Inter-governmental Panel on Climate Change (IPCC) projection period. Secondly, as the period is most recent it is easy to recall and, therefore, most appropriate for reflecting perceived normal conditions. Data availability, particularly computer coded and processed, also influences the selection of this period. Thirdly, it is desirable to compare present conditions to the future rather than some past climate.

2.4.1. Data and methodology:

Temperature and rainfall data from 38 stations were used to develop the climate baseline (see Fig. 1). Out of these 38 stations, 12 have nearly complete record of 30 years data of temperature and rainfall. The overall data gap is less than 5% and missing daily values were filled by their respective averages. The rest are used as indicators.

To study climate variability, the 1961-1990 average (μ) and standard deviations (δ) were computed for rainfall. In addition, to identify extreme variability such as wet and dry (or drought) years (μ±δ) are processed. Rainfall values more than (μ+δ) are referred to as wet years while those values less than (μ-δ) are taken as dry (drought) years. Values falling within (μ±δ) are defined as oscillations within the normal range. A three years moving average was also computed to smooth-out the extreme cases and study trends. In the case of temperature, variability is studied in comparison with the average of the base period. Figures ... depict the mean seasonal rainfall and temperature maps.

2.4.2 Rainfall and temperature analysis

The study of baseline climate has been accomplished by subdividing the country in sub-regions such as southwest, central, eastern highlands/lowlands, etc. and stations were selected to reflect each sub-region’s climatic conditions (see fig.). It is to be noted that the subdivision does not imply homogeneity in climate. It is based on similarity in rainfall regimes and temperature conditions (Workineh, 1987; NMSA, 1996; Alemu, 1998).

Northern and Northwestern highlands:
Rainfall over Gonder and Debre Marcos shows a declining tendency. 1978, 1984 and 1986 for Debre Marcos 1970, 1982 and 1990 for Gonder were drought years.
Temperatures at Gonder were above average between 1972 and 1984 and declined between 1985 and 1989. Above average temperatures in most of the years were recorded in Debre Marcos.

Northeast highlands:
Although rainfall at Combolcha seems to oscillate about the average, a decreasing tendency is significant in most years. There were 3 wet years before 1975 and no wet years thereafter. 1965, 1973, and 1984 were extreme drought years on record (Workineh, 1987) and 1987 was also a dry year.

Temperature records at Combolcha do not signify any appreciable trend. However above average temperatures were recorded between 1986 and 1990.

Northeast lowlands:
Dubti is in a low rainfall zone. It receives little more than 200 mm of rainfall per year on the average. Five of the years were drought while three of them were wet years. An overall picture shows oscillations about the average.

Temperatures at Dubti were below average in most of the years between 1961 and 1979 while they were above average since 1980.

Central Ethiopia:
Addis Ababa rainfall data depicts four drought and four wet years within the period of study. There is no appreciable decreasing or increasing tendency in rainfall. Temperatures were above average since 1979 except 1985.

West and Southwest Ethiopia:
Gore and Jimma records were studied in this sub-region. The rainfall at Gore depicts significant decreasing trend since 1971. Though the moving average line shows oscillation about the average, the annual rainfall at Jimma shows a declining trend between 1961 and 1985. There were three wet and two dry years in this period.

Temperatures at Jimma were above average since 1977 with exception of 1984 and 1985. Gore temperatures were also above average since 1979 except 1985 and 1989.

Southeastern and Eastern highlands and Dire Dawa area:
The general tendency of rainfall over Jijiga is a declining one, particularly records since 1971 were all below the average and 1984 was drought for Jijiga. The first half of the 30 years period depict some four wet years.

Appreciable tendency towards increase or decrease in rainfall has not been identified over Dire Dawa. 1965, 1973, 1979, and 1984 were drought years while 1961, 1964, 1967, 1968, 1982, and 1983 were wet years. However recent records show a declining tendency.

Temperatures at Dire Dawa were above average since 1969. The general tendency of temperature at Jijiga is a rising one and most of the years since 1976 exhibit above average temperatures.

Southern Ethiopia:
Negelle in the south shows below average rainfall since 1983. There were five drought and two wet years during the period under study. Temperatures at Negelle oscillate about the average and recent records were below average. Robe rainfall varies within the (μ±δ) ranges. Temperatures at Robe show a significant increase since 1981.
In summary, it is observed that rainfall was on a decreasing tendency over most of the stations understudy while the condition at some stations was an oscillatory within the defined normal range. Though increasing temperatures were observed at some stations, it has not been systematic and too difficult to associate with the global warming event. The short duration of records has contributed to this difficulty.

III. CLIMATE CHANGE SCENARIOS

In order to assess the impacts of climate change, it is essential to obtain a quantitative representation of the changes in climate themselves. It is desired that the climate change scenarios have to be checked against accepted projections and must meet the following conditions (Houghten et al., 1990; Carter et al., 1992; USCSMT, 1994; Smith et al., 1998):

- consistency with the projections of climate change;
- physical plausibility, i.e., they do not violate the basic laws of physics;
- estimate of sufficient number of variables on spatial and temporal scale needed for vulnerability assessment; and
- they should reflect potential regional climate changes.

There may be various tools and methods of obtaining future climate. Amongst them: palaeoclimatic analogue scenarios, arbitrary adjustments (or incremental scenarios), and scenarios from the General Circulation Models (GCMs) are often used by the research community (see Cubasch & Cess, 1990; Carter et al., 1992; USCSMT, 1994; Smith et al., 1998 for details). Due to unavailability of data palaeoclimatic methods are not used. Here GCMs and incremental methods are employed.

A simple method of specifying a future climate may be to adjust the baseline climate in a systematic, though arbitrary, manner. These are called incremental scenarios (or arbitrary adjustments). They capture wide range of climate change and can identify sensitivity to individual climate variables. Their drawback is that the changes may not be physically plausible and they may contain large area and missing variables (Carter et al., 1992; USCSMT, 1994).

The other tools available are the GCMs. GCMs are based on laws of physics. They are used to estimate the likely future effects of increasing green house gas (GHG) concentrations on climate. The advantages of using the GCMs are: consistency with estimate of climate change, physical plausibility, and the option to contain sufficient number of variables. Though regional estimates of current climate from GCMs are often inaccurate and their resolution are limited (see Houghten et al., 1990 for details), they provide a powerful facility. Also reasonable estimates could be obtained by incorporating observed climate. Therefore, five GCM models were examined for use in the study. These are Canadian Climate Centre model (CCCM; Boer et al., 1992), Geophysical Fluid Dynamics Laboratory R-30 model (GFDL R-30; Wetherald and Manabe, 1988), Geophysical Fluid Dynamics Laboratory’s transient models (GFDL-transient; Stouffer et al., 1989), Goddard Institute for Space Studies (GISS; Hansen et al., 1983) model and the United Kingdom Meteorological Office Model (UKMO-89; Mitchell et al., 1989). It is to be noted that equilibrium models future climate for the year 2075 while the transient models give estimates in decadal time step (1st for 2010s, 2nd for 2020s, 3rd for 2030s 4th for 2040s, 5th for 2050s, 6th for 2060s and 7th for 2070s).

3.1 Data and Methodology

3.1.1 Data

Both current (1*CO2), double (2*CO2) and transient statistics data are provided by the National Center for Atmospheric Research (NCAR) in appropriate formats and are used in this study.

3.1.2 Methodology
a) Methods for incremental scenarios:
Future climate change scenarios using incremental changes were developed as follows:

Temperature: \(2 \times 4^\circ C + \text{observed data} \)
Rainfall: \((-10\%, -20\%, 0, +10\%, +20\% \text{ changes}) + \text{observed data} \)
Using this method, Tables - - and - - prepared for use in vulnerability studies.

b) Methods for GCM scenarios:
To develop scenarios from the GCMs a 0-30°N and 30-60°E latitude-longitude window has been created. The procedure followed for developing climate change scenarios from equilibrium and transient GCMs is as follows:

**Equilibrium GCMs:**
- Temperature: \(2 \times \text{CO}_2 - 1 \times \text{CO}_2 + \text{observed data} \)
- Rainfall: \(2 \times \text{CO}_2 / 1 \times \text{CO}_2 + \text{observed data} \)

**Transient GCMs:**
- Temperature: Decadal averages + observed data
- Rainfall: Decadal averages + observed data
Grads software (Doty, 1992) facility is used to extract temperature differences and rainfall ratios from GCMs.

3.2. Validation process of GCM simulations and model selection

Validation involves comparison of current model simulation with the observations to test performances. Then selection of models that better reflect the observed climate has been done by adopting the following criterion in a 0-30°N and 30-60°E window.

- **Comparison results of current simulation with average climate (temperature and rainfall).**
  Grads software (Doty, 1992) was used to produce current (1*CO₂) GCM output maps for the region being studied. Observed data and 1*CO₂ outputs from the GCMs were compared based on the location, the magnitude (how significantly the GCM under or over estimates climate), and the number of maxima and minima. The gradient and how accurately the model simulates the marginal areas (the boundary between the lowlands and highlands) were also examined.

- **Model resolution.** Most models have low resolution, do not parametrize the physiographic nature of different places well, and use a generalized topography. Since Ethiopia exhibits different types of terrain features, the low resolution models give exaggerated estimates.

- **Trend match.** In addition, validation was done on station by station basis. **Gridpti** program (developed by NCAR) was used to interpolate temperature differences and rainfall ratios from GCM for selected stations. GCM outputs were compared to actual climate data. Trends and the trend match between the two results were studied (see fig.).

Validation assessment was done on seasonal basis for Kiremt (June-September), Belg (February-May) and Bega (October-January) (see Workineh, 1987; NMSA, 1996; Ademe, 1998 for description). The baseline climate data (1961-1990) was organized in compatible units of measurement. For example, a rainfall baseline map was prepared in mm/day (see fig. - -).

3.3 Validation assessment on seasonal basis:

**Temperature** (see Fig.):

**GFDL-R30:**
The model simulates as if cooler area extends from Central Ethiopia into Eastern highlands neglecting the warmer zone in the central Rift Valley. Center minimum values are higher than the observed by about 1-2°C for all seasons. The temperature gradient from Central Ethiopia and Eastern highlands towards the lowlands of northern Rift Valley and Southeastern lowlands are underestimated. The north-south oriented cooler zone of northern highlands and the adjoining lowlands are simulated as if they have uniform temperature. Northern highlands are simulated as if slightly warmer by about 2-3°C than the actual in the Kiremt season. The general eastward increase of temperature is well simulated.

**CCCm:**
This model simulates a single minimum center covering a wider area of Central Ethiopia. Simulations show that temperatures uniformly increase towards the lowlands with a weak gradient as compared to the observed climate where gradient towards the northern Rift Valley is strong. Temperatures over the lowlands are underestimated.

**GFDL-Transient:**
Simulation from this model is rather poor. Uniform temperature from southwest to northeast is shown.

**UKMO (UKMO-89):**
The simulations show central temperature minima over eastern parts of Central Ethiopia for the Kiremt season. Bega seasonal temperatures are overestimated by about 3-4°C and Belg temperatures are overestimated by about 4-6°C.

**GISS:**
The model does not show spatial temperature differences between the highlands and lowlands. It also over estimates current temperatures.

**In general:**
- Most models couldn't discriminate the temperature gradient between lowlands and the adjoining highlands.
- Simulations of the northern Rift Valley and Southeastern lowlands from most models are underestimated.
- All model simulations show increasing temperature trends from Central highlands towards the east.

**Rainfall (Refer to Fig.):**

**GFDL-R30:**
This simulated only one rainfall maximum for all seasons with the center slightly shifted to the south as compared to the actual. The simulation generally agrees with the observation in respect to depicting the eastward and northward gradual decrease from the high rainfall pocket areas in the Southwest. The model overestimates by about 3-8 mm/day over the high rainfall areas.

**CCCm:**
This model simulated the Bega season better than other models. Though the model identified single maxima for all seasons, it picked well the high rainfall zone and the gradient from the high towards the low rainfall zones. In general, it overestimates by about 1-5 mm/day.

**GFDL-Transient:**
This model underestimated the Kiremt rainfall all over the country. In most cases the high rainfall center is located as slightly shifted to the south as compared to the actual position.

**UKMO (UKMO-89):**
The model simulated northeast-southwest oriented high rainfall center extending from 8°-12°N for the Kiremt season. The rainfall gradient from the high center to low areas is weak. Seasonal rainfall is underestimated by about 2-3 mm/day.

GISS:
The simulation form this model shows big differences compared with the current rainfall climate. The rainfall pattern is not captured.

In general:
- All models simulated only one rainfall maximum for the country while the actual shows more than one high rainfall pocket areas.
- All models could not discriminate the lowlands with the adjoining highlands. This may be due to the inherent problem of the models since they use smoothed topography.
- All models are weak in identifying the high rainfall zone over the eastern highlands and overestimated the rainfall of northern Rift Valley.
- All models overestimated the rainfall over northwestern and southeastern lowlands particularly for the Belg season.

Using the above set criterion and validation results, therefore, two equilibrium and one transient GCM models that better simulate the mean climate were selected. These are Canadian Climate Centre Model (CCCm), the Geophysical Fluid Dynamics Laboratory-R30 (GFDL-R30) model, and the Geophysical Fluid Dynamics Laboratory's transient (GFDL-transient) model. However, UKMO gives estimates of more than 4 degrees which seem unreasonable. GISS is a low-resolution model and estimates are often inaccurate. Thus, UKMO and GISS will not be used in developing climate change scenarios.

3.4 Climate Change Scenarios for Ethiopia: Results and Discussion

Temperature Scenarios (see fig):

KIREMT:
All models project a general increase in temperature. Specifically, the GFDL-R30 estimates an increase ranging from 2.4 - 3.3°C for most parts of the country and about 3.6 changes over central Bale. CCCM showed an increase from 2.0-2.5°C for most parts. GFDL-transient shows a projection of 0.8-2.4°C changes in temperature.

BELG:
All models project a general increase in temperature. GFDL projected a change from 2.2-3.2°C. CCCM model exhibited a change from 2.2-3.6°C. GFDL-transient projected a change ranging from 0.5-1.2°C.

BEGA:
A general increase is projected. GFDL showed from 2.4-3°C changes. CCCM gives 1.5-2.5°C changes. GFDL-transient projects 0.9-1.4°C changes.

It is noted that among the models used, GFDL-R30 projected changes were high (up to 3.5°C) while GFDL-transient gives projections in lower ranges.

Rainfall Scenarios (see fig):

KIREMT:
An increase by slightly less than 10 to 20% is projected for places north of 8 degrees and west of 41 degrees longitude by GFDL. CCCM projects an increase by more than 50% over northern-most parts while decrease
projected an increase by about 50% for northern extreme areas. The transient model projected a decrease. For the Belg season, all models estimate an increase of rainfall by about 5% over Southwest, South and Southeast and a decrease over northern parts. For the Bega season, all models project a general increase in rainfall.

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Environmental Protection Authority (in collaboration with the Ministry of Economic Development and Cooperation, Ethiopia), 1997a. Environmental Policy. Environmental Protection Authority, Addis Ababa.


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* Stations with 30 years (1961-90) data
Fig. 4. Comparison of observed and GCM estimates of current climate: Rainfall

Fig. 5. Comparison of observed and GCM estimates of current climate: Temperature
Fig. 6a CCCM, GF01 & GFD3 model outputs of Rainfall and Temperature for 1XCO2 and changes/ratios (Kiremt).
Fig 6b  CCCM, GF01 & GFD3 model outputs of Rainfall and Temperature for 1XCO2 and changes/ratios (Bulg).
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**Note:** The table continues with similar entries for other dates and stations.
Table 3: Scenarios of Temperature over selected stations for transient period; GF4 (2010) & GF7 (2040) Based on GFDL Transient GCM

Table 4: Scenarios of Rainfall over selected stations for transient period; GF4 (2010) & GF7 (2040) Based on Transient GCM