International Journal of Scientific & Engineering Research Volume 11, Issue 8, August-2020
ISSN 2229-5518

MADAWALABU UNIVERSITY

SCHOOL OF NATURAL SCIENCE

PRGRAM OF ENVIRONMENTAL SCIENCE (STREAM ENVIRONMENTAL RESOURCE MANAGEMENT)

THE ECONOMIC IMPACT OF CLIMATE CHANGE ON AGRICULTURAL CROPS IN BALE ZONE, SOUTH EASTERN ETHIOPIA

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June, 2015

Bale- Robe

International Journal of Scientific & Engineering Research Volume 11, Issue 8, August-2020
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A thesis Presented to the school of Natural Science, Graduate Programe of Madawalabu University in Partial fulfillment of the Requirement for Degree of Masters of Science in Environmental Science.

By Begna Duressa

International Journal of Scientific & Engineering Research Volume 11, Issue 8, August-2020
ISSN 2229-5518

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1. **Demeke Datiko**__________ ________________________

2. **Yoseph Kanaa**_____________________ ___________________________

ACKNOWLEDGMENTS

My first and foremost appreciation and thanks go to my Major advisor, Dr. Demeke Datiko for his effort, passionate and unreserved support, guidance, encouragement and patience which contributed to the success of this study.I would also like to express my especial gratitude to my co-advisor Yoseph Kanaa for his devoted support with his gentle advisor-ship skills starting from the early stage of the design of the research to the final write-up of the thesis by adding valuable, constructive and ever-teaching comments which were always remembered throughout my life. Besides, his patience to back my statistics and above all to introduce me with the concept of Statistical Down Scaling Modeling from the scratch and guidance throughout the progress of the work were highly appreciated. Without his encouragement, guidance, and help; this work would not have taken this shape. I feel fortunate to have got this opportunity to work with him.

I am thankful to Fisaha Shifera, Asnakech Adineow and Feyisa Ture for their invaluable moral support, which significantly contributed encouragement and advice during the course of my study. I am very grateful to Mr. Dame Hunde for his valuable contribution in GPS.

My special thanks goes to my wife Addisalem Tesfaye for her invaluable encouragement throughout my study period and love, especially when our daughter Honey was born.

Finally, I would like to acknowledge all individuals who assisted me directly or indirectly during the course of my study.

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ACRONYMS

ABW	Arsi Bale Wheat Livelihood
ANOVA	Analysis of Variance
BoFED	Bureau of Finance and Economic Development
BZFEDO	Bale Zone Finance and Economic Development Office
CCCSN	Canadian Climate Change Scenarios Network
CGCM1	Canadian Global Coupled Model Version 1
DP	Dia- Ammonium Phosphate
DPPOEWB	Disaster Prevention and Preparedness office early Warning Bulletin
EU	European Union
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
GDP	Gross Domestic Product
GPS	Global Position System
H3A2a	Hadley Centre Coupled Model forced with the A2 emission scenario
HaDCM3	Hadley Centre Coupled Model Three
HEA	Household Economic Approach
HH	Household
HH	Household
IBM	International Business Management
ICPAC	International Climate Predication and Adaptation Center
IPCC	International Panel for Climate Change
MEDaC	Ministry of Economic Development and Cooperation
MoFED	Ministry of Finance and Economic Development
NAPA	National Action Plan for Adaptation
NCEP	National Centers for Environmental Protection
NMA	National Metrological Agency
NMSA	National Meteorological Services Agency
NRPH	Net Revenue Per Hectare
OECD	Organization for economic Co Operation and Development

Oxfam PA's
SDSM SRES
UNOHRLLS UNDP
UNFCCC

Oxford Committee for Famine
Peasant Association
Statistical Downscaling Model
Special Report on Emissions Scenarios
United Nation Office of the high representative for the least developed
United Nations Development Programme
United Nations Framework Convention on Climate Change

ABSTRACT

The study examined the extent of the economic impact of climate change on crop production in Bale zone (Sinana, Ginir, Goro and Gololcha) as a result of marginal effects of temperature and rainfall, as well as investigated the degree of observed climate change downscaled future projection. It also assessed the perception of the local community on climate change and adaptations mechanisms employed by farmers in response to climate change in the study area. A cross sectional survey at household farm level were conducted in four districts, selected by considering significant representation of all the agro ecology of the zone. In the first part of the study, a Ricardian approach was adopted in which two regression models, climate and other control variables were conducted to assess the impact of climate change on net revenue per hectare. The estimated results indicated that climate change mainly temperature and precipitation are very influential for agricultural activities and climate impact also found to have linear and quadratic relationship with net revenue. The estimated results obtained from analysis of marginal effect indicated that there was significant effect of climate change on net revenue from crop production. Increasing temperature marginally during the fall season will increase the net revenue per hectare and increase in the square of summer temperature marginally reduces the net revenue per hectare. Even though there are increasing as well as decreasing tendencies in precipitation, it is found that precipitation is not significant in the regression model.

With regards to the investigation of the degree of observed climate change downscaled for future projection, the outputs of HadCM3 GCM model for the A2a and B2a emission scenarios were used to produce the future scenarios. The SDSM downscaling model was adopted to downscale the global scale outputs of the HadCM3 model outputs into the local level. Accordingly, both the A2a and B2a scenarios have shown increasing tendency of annual maximum temperature of 0.13^{0}C and 0.3^{0}C per annum respectively by 2080 for Ginir station. The base year model fit was found good for both A2a and B2a scenarios. As obtained from the modeled result, the fall maximum temperature of Ginir station was found to increase by 1,25^{o}C with the A2a scenario and decrease by 0.08^{o}C for the B2a scenario. Similarly, summer maximum temperature for Ginir station at 2080 was found to decrease by 0.71^{0}C with A2a scenario and decrease by 0.15^{0}C with the B2a scenario. Thus, this study suggested that increase in the fall temperature and decrease in the summer temperature will result in a significant increase in net revenue per hectare at Ginir by 2080 for the A2a scenario. For the B2a scenario, still increase in net revenue is expected if not as such large when compared to the A2a scenario.

Key words: *Adaptation, Climate Change, Climate Change Impact, Climate Change Modeling, Statistical Downscaling Model, Ricardian Model ,Weather*

International Journal of Scientific & Engineering Research Volume 11, Issue 8, August-2020
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1. INTRODUCTION

1.1 Background of the Study

Climate change is not a new phenomenon in the world. The rise in temperature of the earth surface and in atmosphere, fluctuation in rainfall, declining ground water, flooding due to high rainfall, drought, soil erosion, heavy wind, rising sea level due to melting of glacier, cyclone, wind speed, hail storm, fog, earthquake and landslide are all the clear evidence of climate change phenomenon. Though it is a natural process but in some cases human activities are also responsible for this. There are many examples across countries where increase in the possibilities of climate change due to growing population, rapid urbanization, higher industrialization, use of modern technology, innovation, higher economic development, transport, building construction, reduction in forest area etc. are observed (*Ahmad et al., 2011*).

The Fourth Assessment Report (IPCC, 2007). emphasizes that there will be changes in the frequency and intensity of some weather events and extreme climate events which will likely challenge human and natural systems much more than gradual changes in mean conditions. In mid, high latitude and higher income countries climate change has positive impact on agricultural production or crop yield, and on the other hand, lower-latitude and lower income countries experience a negative effect on agricultural production. Moreover, developing countries are most vulnerable compared to developed countries. There are many reasons which increase the vulnerabilities for developing countries like low level of technological progress, lack of resources to mitigate the adverse effect of climate change on agriculture; and due to their greater dependence on agriculture for livelihood of large populations (Nath and Behera, 2011).

Climate and its variability impact in all sectors of economy like abnormality in rainfall, results in severity and frequency of floods. Climate change adversely affects the food security in all countries through agriculture production. It affects food security in four dimensions such as, food availability, food accessibility, food utilization and food system stability. It will also have an impact on human health, livelihood assets, food production and distribution channels (FAO, 2008). Widespread research findings have revealed that climate variability and change have significant impacts on global and regional food production systems particularly on the performance of common staple food crops in the tropical sub-humid climatic zone (UN-OHRLLS, 2009). The most food insecure regions and most climate change vulnerable regions in Ethiopia are those that experience both the lowest and most variable rainfall patterns (UN-OHRLLS, 2009). Climate change is

International Journal of Scientific & Engineering Research Volume 11, Issue 8, August-2020
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therefore, directly or indirectly affecting the agricultural production of the area through influencing the emergence and distribution of crop pests, livestock diseases, aggravating the frequency and distribution of adverse weather conditions, reducing water supplies and enhancing severity of soil erosion among other impacts (Watson, 1998). Climate variability and its associated impacts are inducing frequent crop failures, and declining livestock production and productivity leading to aggravated rural poverty in the region. Temperatures and changing precipitation levels as a result of the changing climate will further depress agricultural crop yields in many arid-and semi-arid parts of Ethiopia over the coming decades (Bezabih et. al., 2010).

Ethiopia is extremely vulnerable to the impacts of climate change due to social, economic and environmental factors. In particular, high levels of poverty, rapid population growth, a high level of reliance on rain-fed agriculture, high levels of environmental degradation, chronic food insecurity and frequent natural drought cycles increase climate change vulnerability in this country. Climate change have a notable impact on Ethiopia's temperature and precipitation: average annual temperatures nationwide are expected to rise by 3.1° C by 2060, and 5.1° C by 2090. In addition, precipitation is projected to decrease from an annual average of 2.04 mm/day (1961-1990) to 1.97 mm/day (2070-2099), for a cumulative decline in rainfall by 25.5 mm/year (Amsalu and Adem 2009).

In Oromia region, most of the agricultural agriculture activities are rain-fed with small scale farming which provides livelihoods for 85 percent of the population. Oromia accounts for about 51% of crop production in Ethiopia. The extreme variability in climate severely affects the economy of the region and the country in general. According to Oxfam International (2010), increasing temperature and rain fall variability have been prevailed in the region since the last five decades and posed significant impacts on the livelihoods of the people. Particularly crop production is considered the sources of the country's agricultural surplus. It is also the major sources of food supply for the country's major urban centers and deficit areas. However, it is heavily affected by these changes (*Mahammed Hansen et al., 2004*). With current intensity and pattern of climate variability or change, the country is facing resultant adverse effects of climate change. There is no a single social or economic sector in the region which is expected to be free from climate change-induced impacts and shocks. Almost all sectors are vulnerable to impacts of climate change. But, the most vulnerable sectors to climate change in the context of the Oromia regional state include: Agriculture (crop cultivations and livestock rearing), water, health, forests, pastures and biodiversity. The magnitude of vulnerability and degree of sensitivity to climate change-induced shocks and hazards vary from sector to sector. In terms of livelihood means, smallholder rain-fed farmers and pastoralists in the region are found to be the most vulnerable to climate change shocks and the arid, semiarid and the dry sub-humid parts of the region are most affected by drought (BoFED, 2008).

1.2 Statement of the Problem

Climate change is a long term change on average weather condition (FAO, 2008). It was in the late 1970's that climate change recognized as a global environmental phenomenon (Abatzoglou et al, 2007). The implication of changes in temperature, variation in rainfall pattern and sea level is a key factor of climate change affecting economic and social patterns and natural system for present and future generations. The recent IPCC Fourth assessment report indicates that climate change will have significant impact on crop production and water management systems in the coming decades. In addition, there is a potential for earlier negative surprises linked to increased frequency of extreme events. The strong trends in climate change that are already evident, the likelihood of further changes and the increasing magnitude of potential climate impacts particularly in the mid-latitudes and tropical regions (but globally also) gives additional urgency to address agricultural adaptation more coherently (IPCC, 2007).

Ethiopia is one of the examples of how climate change affects Africa (Haakansson, 2009). Based on UNDP (2007/2008) human development report, 46% of the population in Ethiopia is malnourished and 77.8% of the population earns less than two US dollars a day. Moreover, The World Bank (2012) stated that Ethiopia is one of the countries extremely vulnerable to drought and natural disasters such as flood, heavy rain, frost and heat weaves. This extreme weather, because of the impact of climate change, causes the loss of peoples and livestock's life, livelihoods of farmers and their properties disrupts.

Climate change presents a substantial challenge to agricultural development. Fluctuating rainfall and the occurrence of drought are the intrinsic feature of midland and lowlands of Bale zone. Drought and floods have become a constant challenge throughout the zone. A phenomenon which was occurring every five years before one decade is now taking place much more frequently, though, the effects are less. Since the drought frequency of the event has become almost annual there are communities who are perpetually affected every season. Their vulnerability is becoming high and sustainable solutions seemed to be lacking. It is all kind of likelihood that natural and man-made will only continue to happen in the future, perhaps with increasing severity and frequency (BZDPPOEWB, 2013).

Agriculture which is influenced by a wide range of climatic, ecological and topographical diversities is the backbone of Bale zone economy with the engagement of the majority of the population which accounts 89%. However, the dependency of most of the farmers on rain fed agriculture has made the zone agriculture economy extremely vulnerable to the effects of weather and climate change. As a result, failure of rains and occurrence of drought or consecutive dry spells during the critical growing season leads to crop failure which in turn leads to food shortage.

The magnified and frequency of food shortages that arises from adverse weather conditions has increased considerably in recent year. According to BZDPPOEWB (2013), in the study areas the challenges may range from household food insecurity to unsustainable management of natural resources, deforestation, erratic rainfall, excessive rainfall and population pressure that are key for agricultural development governing the welfare for a number of the rural poor. Changes in rainfall pattern are likely to lead severe chronically food insecurity, water shortages and flooding. Rising temperature will also cause shifts in crop growing seasons which affects food security. The magnitude of drought and flood are also considered to have the most adverse effects on crop production in most of the districts. Moreover, this recurrent drought worsened the situation particularly in four districts of which three of them are identified as one of the food deficient districts of the region being categorized as chronically food insecure districts with a substantial food aid is being distributed annually.

In previous period, there was no research studies conducted in the selected districts considering, the complex and interrelated consequence of climate change crisis situation and the impact of climate change on Agricultural production. Hence, the study analyzed the current and potential impacts of climate change on major food crops (wheat, Barley, teff and Maize). Even though there are general perceptions on climate changes and its impacts, none have been studied to measure the extent of the impacts on agricultural production in the study area.

1.3 Significance of the Study

The problem of climate change is widely studied in the world. The impact of the climate brings series damage especially in developing countries. Ethiopia faced a lot of challenges that resulted from climate variation even though the degree of the climate change is not clearly identified. The frequency of the occurrences of climatic hazard has increased. Moreover, the magnitude of climate change has been increasing from time to time and has affected livelihoods. Variations that occur on rain fed agricultural have severe impact and also resulted in environmental degradation as well. However, expansion of drought is a major problem in Bale zone especially, in 13 food in secured districts as most parts of the zone are being affected by drought due to climate change. Hence, the study played a significant role to enhance and facilitate exchange of climate knowledge and information among local communities, field experts and researchers as well as climate-resilient agricultural production systems for improved livelihoods of people in the study area. Moreover, the study also provides necessary information on climate change impact for Bale zone governmental sectors especially Agriculture office, Disaster prevention and preparedness office, Water, Mineral and Energy office, and NGOs interested in promoting rural development in the study area will be benefited from this study. The result of this study can also be used as a source of information to other researches to be conducted in the same ecological zones in the future.

1.4 Objective of the Study

1.4.1 General Objective

The general objective of this study is to investigate whether climate change and adaptation have any impact on food crop production and/or farm net revenue in the study area.

1.4.2 Specific Objectives

- To describe the observed monthly rainfall and temperature variability of the study area during the last thirty years and compare it with the downscaled data obtained from Global sources HaDCM3.

- To examine the net revenue impact of predicted climate scenarios from HaDCM3 for the period 2020, 2050 and 2080.
- To assess the perception of the local community on climate change and its impacts in the study sites
- To assess whether a farmer of the study site had adopted any measure in response to the perceived changes in climate

1.5 Hypothesis

- There is a significant impact of rainfall and temperature variation on crop production in the study areas
- There is a significant difference of climate change variation in the four districts
- The net revenue from agricultural crop production might decrease in the study area by 2080s period due to the impact of climate change.

1.6 Scope of the Study

In this study, four districts namely, Sinana, Ginir, Goro and Gololcha are among the 18 districts of the zone which are purposively selected for the study to analyze the economic impact of climate change on crop production. Since it is impossible to cover the whole aspects of the study area to assess the impact of climate change on food crops revenue with the available time. Therefore, this forced to limit the scope of the problem to a manageable objective. Hence, the study was focused on the economic impact of climate change on crop production using primary data collection tools like household surveys and climate model HaDCM3. Finally, adaptation mechanism to climate change effect was setting

1.7 Definitions

Climate Change: - Climate change refers to the statistically significant change in the measurements of either the mean state or variability of the climate for a place or region over an extended period of time either directly or indirectly due to the impact of human action on the composition of the global atmosphere or due to natural variability (Twigg, 2007).

Weather: is the day-to-day state of the atmosphere and its short-term (from hours to a few weeks) variations such as temperature, humidity, precipitation, cloudiness, visibility or wind (Ramamasy *et al.*, 2007).

Adaptation: The adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (UNFCCC, 2007). **Downscaling:** Downscaling is a technique for exploring the regional and local-scale response to global climate change as simulated by comparatively low-resolution global climate models (GCMs) (IPCC, 2001).

2 LITERATURE REVIEW

2.1 Climate in Ethiopia

2.1.1 Past Trends of Climate in Ethiopia

Ethiopian climate is characterized by a history of climate extremes, such as: droughts and floods; and increasing and decreasing trends in temperature and precipitation, respectively. The history of climate extremes, especially drought, is not a new phenomenon in Ethiopia. Recorded history of droughts in Ethiopia dates back to 250 BC. Since then, droughts have occurred in different parts of the country at different times (Webb and von Braun, 1994). Even though there is a long history of drought in Ethiopia, studies show that the frequency of droughts has increased over the past few decades, especially in the lowlands (Lautze *et al.*, 2003; NMS, 2007). Studies also indicate that mean temperature and precipitation have changed over time. According to NMSA (2001), the average annual minimum temperature over the country has increased by about 0.25^{o}C every 10 years, while the average annual maximum temperature has increased by about 0.1^{0}C every decade. The average annual rainfall of the country showed a very high level of variability over the past years, even though the trend remained more or less constant (NMS, 2007).

2.2 Agriculture in Ethiopia

Agriculture remains by far the most important sector in the Ethiopian economy for the following reasons: (i) it directly supports about 85% of the population in terms of employment and livelihood; (ii) it contributes about 50% of the country's gross domestic product (GDP); (iii) it generates about
88% of the export earnings; and (iv) it provide around 73% of the raw material requirement for agro- based domestic industries (MEDC, 1999). It is also the major source of food for the population and hence the prime contributing sector to food security. In addition, agriculture is expected to play a key role in generating surplus capital to speed up the country's overall socio-economic development (MEDC, 1999).

Ethiopian agriculture is predominantly characterized by traditional methods of farming with very little change in farming practice over the past few years. The continuous use of such farming practice over a long period of time with little or no soil conservation measures has significantly eroded the fertility of the soil and agricultural outputs (Degefe, 2000). The major factors behind the poor performance of Ethiopian agriculture are diminishing farm size and subsistence farming, soil degradation, inadequate and variable rainfall, climate-related disasters, tenure insecurity, weak agriculture research base and extension system, lack of financial system, imperfect agriculture markets and poor infrastructure. Ethiopian farming largely produces only enough food for the peasant holders and their family for consumption, leaving little to sell. Crops are the major production and sources of food in the country since most of the population depend on agriculture (Degefe, 2000).

2.3 Vulnerability of Ethiopian Agriculture to Climate Change

The vulnerability of Ethiopian farmers to climate change is attributed to their dependence on rain-fed agriculture and high poverty. Rain-fed agriculture, which supports the livelihoods of the majority of the population, is highly sensitive to climatic conditions. It is characterized by: highly erratic rainfall; frequent droughts that often cause famines; and intensive rainfall that often cause floods. Given the dependence of the economy on agriculture and the dependence of the agricultural sector on climatic conditions, especially rainfall, the macroeconomic performance of the country follows rainfall patterns. Low levels of economic development or poverty is the other source of vulnerability of Ethiopian farmers. The majority of Ethiopian farmers have limited capacities to mitigate, adapt or cope with effects of climate extreme events such as droughts, which significantly reduce the already low consumption. In addition to creating severe food shortages, experiencing a drought at least once in five years lowers per capita consumption by about 20 percent (Dercon *et al*., 2005).

Moreover, Dercon (2004) indicated that rainfall shocks have a substantial impact on consumption growth which persists for many years. Both household and public level climate risk management through mitigation and coping practices are undertaken to reduce the damages from climate change. Risk mitigation strategies at household levels include: crop diversification; mixed crops and livestock production; keeping multiple species of livestock; and joining rotating credit groups. Coping strategies at household level include: selling productive assets; selling of livestock and agricultural products; reducing current investment and consumption; child labour; temporary or permanent migration; mortgaging of land; and use of inter-household transfers and loans. A country level study conducted by MoFED (2007) on the ability of farmers to cope with shocks revealed that the main coping strategies include: sellings of animals (40%); loans from relatives (18%); selling of crop outputs (14%); and own cash (9%).

2.4 **Climate change and its Impacts in Ethiopia**

Ethiopia is historically prone to extreme weather events. Rainfall in Ethiopia is highly erratic, and most rain falls in convective storms, with very high rainfall intensity and extreme spatial and temporal variability. Since the early 1980s, the country has suffered seven major droughts, five of which led to localized famines, in addition to dozens of local droughts (Diao and Pratt, 2007). Survey data show that between 1999 and 2004 more than half of all households in the country experienced at least one major drought shock (*Dercon et al., 2005*), cited in UNDP 2007). Major floods occurred in different parts of the country in 1988, 1993, 1994, 1995, 1996, and 2006 (ICPAC, 2007).

Baseline climate that was developed using historical data of temperature and precipitation from 1971-
2000 for selected stations in Ethiopia showed the year-to-year variation of rainfall for the period between 1951 to 2005 over the country expressed in terms of normalized rainfall anomaly averaged

for 42 stations (NMA, 2007). The country during those periods (1951 to 2005) has experienced both dry and wet years over the last 54 years. Annual rainfall is likely to decrease throughout most of the African region, with the exception of Eastern Africa, where annual rainfall is projected to increase. These changes in the physical environment are expected to have an adverse effect on agricultural production, including staple crops such as wheat and maize. Trend analysis of annual rainfall in Ethiopia shows that rainfall remained more or less constant when averaged over the whole country while a declining trend has been observed over the Northern and Southwestern Ethiopia (IPCC, 2007).

As mentioned in NMA, 2007, the year to year variation of annual minimum temperatures within Ethiopia for the period 1951 to 2005 was expressed in terms of temperature differences from the mean and averaged over 40 stations. The result showed that, the country has experienced both warm and cool years over the last 54 years. However, the recent years are the warmest compared to the early years. Moreover, the result clearly revealed that there has been a warming trend in the annual minimum temperature over the past 54 years. It has been increasing by about 0.37^0 C every ten years.

2.5 Variability of Precipitation and Temperature in Ethiopia

Ethiopian agriculture is smallholder and rainfall dependent; it makes use of traditional technologies. Eighty-seven percent of rural households work less than two hectares (ha) of land, and 64.5 percent of them cultivate less than one (Gebreselassie**,** 2006). The agricultural sector is predominantly in the hands of smallholdings, mostly private peasant holdings, with traditional farming, which depend on rainfall. Agricultural production is subjected to wide variation due to variation of rainfall in magnitude and distribution both in space and time. Moreover, the agriculture in Ethiopia is practiced under the condition of diminishing farm size, high soil degradation, inadequate and variable rainfall, imperfect agricultural markets and poor infrastructure, etc (*Degefe et al., 1999*). The rainfall is highly variable both in amount and distribution across regions and seasons (Tesfaye, 2003). The seasonal and annual rainfall variations are results of the macro-scale pressure systems and monsoon flows which are related to the changes in the pressure systems. The spatial variation of the rainfall is influenced by the changes in the intensity, position, and direction of movement of these rain-producing systems over the country (Temesgen, 2000).

2.6 Climate Change Scenario in Ethiopia

Scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold. A set of scenarios assists in the assessment of future developments in complex systems that are either inherently unpredictable, or that have high scientific uncertainties (IPCC, 2007). Over the coming decades climate change is projected to affect the lives of billions of people around the world. No region or country is invulnerable to its impacts; however, the extent of vulnerability differs widely. Least developed countries (LDCs) and small island developing states (SIDS) are especially vulnerable, though every developing country will face additional challenges to attain the United Nations Millennium Development Goals by 2015 (UNMDG, 2007). Projected climate changes could not only have serious environmental, social and economic implications, but also implications for peace and security and migration. However, the specific impacts of climate change will depend on the climate variance and change it experiences as well as its geographical, social, cultural, economic and political situations. As a result, countries require a diversity of adaptation measures that reflect their unique circumstances (NAPA, 2007).

Future climate change cannot be adequately predicted without a sound understanding of the future expectation of the emission and concentration of greenhouse gases in the atmosphere, which will depend on socio-economic trends including population and economic growth, technological changes and energy demand (Aschalew, 2007). Under intermediate warming scenarios, most models project that by 2050 North Africa and the interior of Southern Africa will experience decreases in precipitation during the growing season that exceed one standard deviation of natural variability; in parts of equatorial East Africa, rainfall is predicted to increase in December–February and decrease in June– August (Aschalew, 2007).

Climate change scenarios for Africa, based on results from several general circulation models using data collected by the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Center (DDC) indicate that future warming across Africa ranging from 0.2°C per decade (low scenario) to more than 0.5°C per decade (high scenario). This warming is greatest over the interior of semi-arid margins of the Sahara and Central Southern Africa (Aschalew, 2007). According to NMA (2007), Climate projections for Ethiopia have been generated using the software MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change)/ (Regional and Global Climate Scenario Generator) coupled model (Version 4.1) for three periods centered on the years 2030, 2050 and 2080. For the IPCC emission scenario, the mean annual temperature will increase in the range of 0.9 -1.1 °C by 2030, in the range of 1.7 - 2.1 °C by 2050 and in the range of 2.7-3.4 °C by 2080 over Ethiopia compared to the 1961-1990 normal. Moreover, a small increase in annual precipitation is expected over the country (Wing *et al.,* 2008).

2.7 Ricardian Approach

The Ricardian approach, pioneered by Mendelsohn et al. (1994), attempts to allow for the full range of compensatory or mitigating behaviors by performing cross-sectional regressions of land prices on county-level climate variables, plus other controls. If markets are functioning well, land prices will reflect the expected present discounted value of profits from all, fully adapted uses of land, so, in principle, this approach can account for both the direct impact of climate on specific crops as well as farmers adjustment of production techniques, substitutions of different crops and even exit from agriculture.

The Ricardian model analyzes a cross-section of farms under different climatic conditions and examines the relationship between the value of land or net revenue and agro-climatic factors (Mendelsohn et al., 1994; Sanghi et al., 1998; Kumar and Parikh 1998; Polsky and Esterling, 2001). This model has been applied to value the contribution that environmental factors make to farm income by regressing land values on a set of environmental inputs and thereby measuring the marginal contribution that each input makes to farm income. Net revenue or price of land can be used to represent farm income. Mendelsohn et al. (1994) used both net revenue and land value, whereas Polsky and Esterling. (2001), used only land value as the dependent variable in their studies of the impact of climate change on the United State's agriculture. Additionally, Sanghi et al. (1998), used land value for Brazil, while Kumar and Parikh (1998) used net revenue as the dependent variable in analyzing the impact of climate change on Indian agriculture.

The most important advantage of the Ricardian model is its ability to incorporate private adaptations. Farmers adapt to climate change to maximize profit by changing the crop mix, planting and harvesting dates, and a host of agronomic practices. The farmers' response involves costs, causing economic damages that are reflected in net revenue. Thus, to fully account for the cost or benefit of adaptation, the relevant dependent variable should be net revenue or land value (capitalized net revenues), and not yield. Accordingly, the Ricardian approach takes adaptation into account by measuring economic damages as reductions in net revenue or land value induced by climatic factors. The other advantage of the model is that it is cost effective, since secondary data on cross-sectional sites can be relatively easy to collect on climatic, production and socioeconomic factors.

Despite the strengths, there are some drawbacks to Ricardian approach. One of the weaknesses of the Ricardian approach is that it is not based on controlled experiments across farms. Farmers' responses vary across space not only because of climatic factors, but also because of many socio-economic conditions. Such non-climatic factors are seldom fully included in the model. Attempts have been made to include soil quality, market access and solar radiation to control for such effects (Mendelsohn et al., 1994; Kumar and Parikh, 1998). In general, however, it is often not possible to get perfect measures of such variables and thus not all of them may be taken into account in the analysis using this method (Mendelsohn, 2000). The other weakness of the Ricardian model is that it does not include price effects (Cline, 1996). If relative prices change because of the way climate change affects aggregate supply, the method underestimates or overestimates the impact depending on whether the supply of a commodity increases or decreases. This oversight leads to a bias in the calculations of producer and consumer surplus and hence to biased welfare calculations (Cline, 1996).

Mendelsohn and Tiwari (2000) argue that for a number of reasons it is difficult to include price effects carefully using any method. First, for most crops prices are determined in global markets and the prediction of what would happen to each crop needs global crop models. But global crop models are poorly calibrated, so it is difficult to predict what will happen to the global supply of any single crop in a new world climate. Second, the few global analyses completed so far (Reilly et al., 1994) have predicted that the range of warming expected for the next century have only a small effect on aggregate supply. Third, if aggregate supply changes by only a moderate amount, the bias from assuming constant prices is relatively small. Thus, based on the above points, Mendelsohn and Tiwari (2000) argue that keeping prices constant is justified because it does not pose a serious problem in using the model.

The fact that the model does not take into account the fertilization effect of carbon dioxide concentrations (higher CO2 concentration can enhance crop yield by increasing photosynthesis and allowing more efficient use of water) is another weakness of the model (Cline, 1996; Mendelsohn and Tiwari, 2000). In spite of these weaknesses, it can be used to analyze the impact of climate change on agriculture by fully considering the adaptations farmers make to mitigate the harmful effects of the change.

2.8 **Statistical Downscaling Model (SDSM)**

Among the different approaches used for downscaling, the most common approach is the statistical downscaling method. As described by (*Palmer et al., 2004*). this method is advantageous as it is easy to implement, and generation of the downscaled values involves observed historic daily data. The latter advantage ensures the maintenance of local spatial and temporal variability in generating realistic time series data. However, the method forces the future weather patterns to only those roughly similar to historic, which is its demerit. For second part of this study, a model developed based on this statistical approach called SDSM was implemented. The model and its methodology of downscaling are discussed in the following sections.

The Statistical Downscaling Model 4.2.2 was supplied on behalf of the Environment Agency of England and Wales. It is a decision support tool used to asses local climate change impacts using a statistical downscaling technique. The tool facilitates the rapid development of multiple, low–cost, single–site scenarios of daily surface weather variables under current and future climate forcing (Wilby and Dawson, 2004). The software manages additional tasks of data quality control and transformation, predictor variable pre–screening, automatic model calibration, basic diagnostic testing, statistical analysis and graphing of climate data.

3 METHODOLOGY

3.1 Description of the Study Area

The study was conducted in, Sinana, Ginir, Goro and Gololcha Districts of Bale zone, Oromiya Regional State, South-east Ethiopia, where mixed farming and Agro pastoralist are commonly practiced. Among the 18 woredas found in the zone, these woredas were selected for this research as they fulfill criteria outlined for weather impact forecast i.e. affected by recurrent drought, weather station, food insecurity, accessibility and required secondary data for further investigation

Ginir District is located in eastern parts of Bale zone at about 633 km away from Addis Ababa and 130 km east of Robe which is capital town of the zone. It covers an area of 2,384km^2. Geographically, it is located 70.15 north latitudes to 40^0.42 east longitudes. It is bordered in East by Sawena, in Sout East by Rayitu, in South by Goro, in North by Gololcha, and in west by Gasera and Sinana woredas

(BZFEDO, 2013).

Goro district is found in the eastern part of Bale zone, Oromia Regional State. It is about 490 km from Addis Ababa and 60 km east from Robe town the capital city of zone. The district with an area of 2,384 km^2 is bounded by Dawe kachan district to the east, Ginir to the north, Sinana to the West, Gura Damole and Barber to the South. Geographically, it is location at 40^0.28 E longitudes and 7^0.15 N latitude (BZFEDO, 2013).

Gololcha district is found in Bale zone of Oromia National Regional State. It is located at about 550 km away from Addis Ababa, capital city of Ethiopia. The district is 120 km away from Robe, the zonal capital. The area of the district covers 2,392 km$^{2.}$ Geographically, it is located at 7^0.15 N latitude to 40^0.29 E longitudes. It is bounded by Gasera district in the West, Lega-hidha and Sawena in the East, Ginir district and Arsi zone in the south (BZFEDO, 2013).

Sinana District is located in Oromia National Regional State in South Eastern Bale Administrative Zone, 430 km away from Addis Ababa. The area is situated also in the eastern high land belts. Robe town is center of the the woreda center, which is the capital of Bale zone. The area is characterized by highly flat plane topography dominated and the altitude ranges from 1650 to 2400 meters above sea level. Total area of the woreda is 1168km^2 of which 60% is arable. Regarding agro ecology 13.3%,85.84% 0.86% are highland, midland and lowland respectively. The cropping seasons are Meher and Belg contributing respectively 60 % and 40% of the production of major crops.

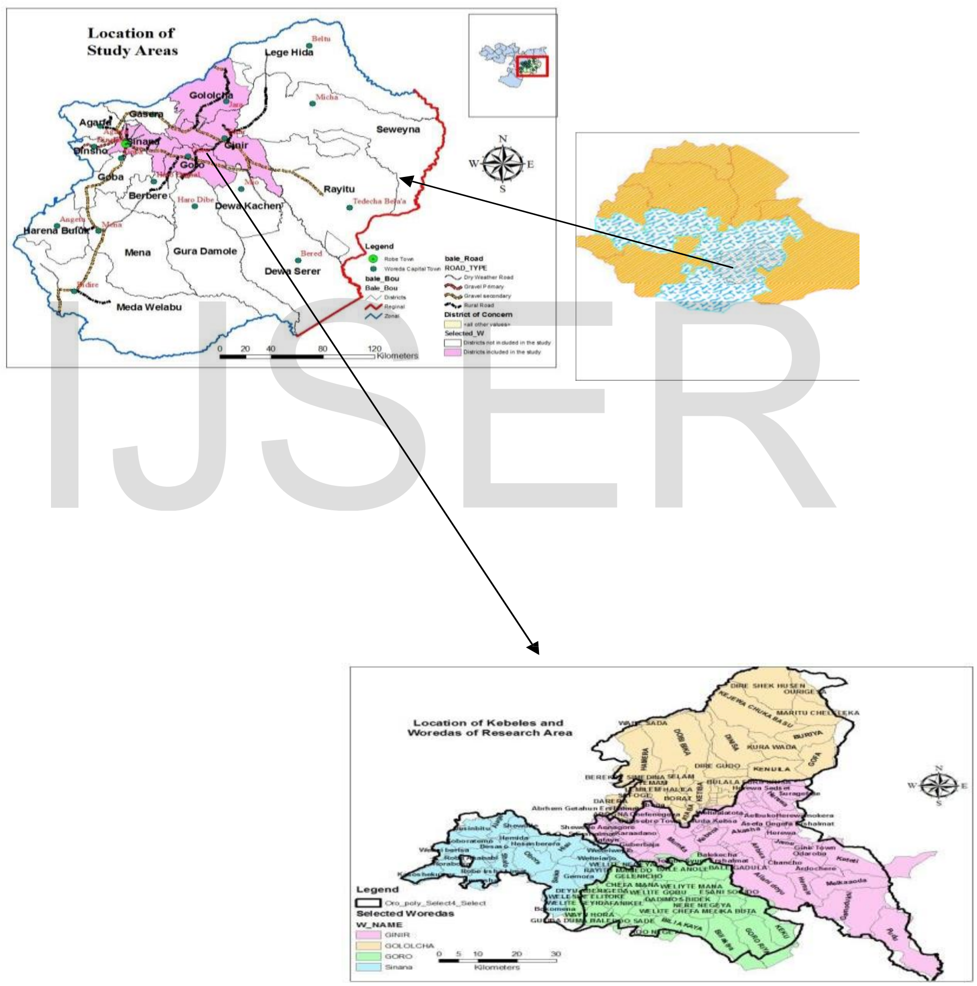

Figure 1 Location of PAs for the study

According to HEA (2008) the community cultivated crop in the study areas are Wheat, Barley and pulse. Thier agro-ecology is divided into highland (dega) and midland (woinadega). The midland areas cover approximately 70% of the zone while the highland covers 30%.The Economic activities of local people are crop and livestock production. The main crops grown are wheat, barley and pulses. The main types of livestock are cattle and sheep.

The topography of the studies are covered by plains, hills and undulating landscape. The vegetation coverage is bush scrub, eucalyptus, acacia, Juniper, and *Hygeinia abyssinica* (or *Kosso*). The geographical features include major and minor mountains and rivers. The daily temperature ranges from 10-25 ^oC, and it is cold in most months. The soil type is clay and vertisoil. The livelihood zone is potentially high in wheat, barley, pulses, rape seed and flax production and is a food surplus area.

Crop production is rain-fed. The main crops for consumption and sale are wheat, barley, pulses, rape seed and flax. Crops are grown in both seasons (*Ganna* and *Bona*). *Ganna* is the most important season for crop production in Bale zone while *Bona* is important for Arsi and West Arsi zones. In their order of importance, the main crops grown for consumption are wheat, barley and pulses while the main crops sold are wheat, barley, pulses, rape seed and flax.

The methods used to prepare land are ox-plow and tractors. Combiners are also used during harvesting period. Wheat, teff, flax and rape seed require higher labor during land preparation, weeding and harvesting. The middle and better-off pay to very poor and poor households during harvesting andweeding time. Crop production is affected by pests and diseases. The main types of pests and diseases are rust, aphids, locust and ball worm. Rust mainly affects wheat and barley; aphids affect wheat, barley and pulses; locust affect all types of cereal and plants and ball worm affect only pulses. Redomil and oxychloride are the treatments used for rust, malathine and roger for aphids, and cultural practices such as fumes for locust and malathine for ball worm are used. The sources of these treatments are either from MoARD or market. The most important inputs used for crop production are fertilizer (DAP), chemicals (24D) and seeds (improved seed such as wheat and barley) HEA (2008).

Cattle, sheep and horse are the main types of livestock reared. Young boys look after cattle while women look after sheep and calves. The method of feeding for these livestock are free grazing and stall-fed. The sources of these feed are grass, crop residue and grains. In the wet season, the source of water for livestock are major and minor rivers, ponds and springs while in dry season, the only sources are major and minor rivers and springs. Cows are the only animals that are milked. Cattle and sheep are sold to generate income for households. Livestock products such as milk, butter, skin and eggs are also sold. Oxen are mainly replaced from within the herd and sometimes by purchase while milking cows are replaced only from within the herd. Animals (mainly sheep) are slaughtered during holidays usually in September (New year), December (Christmas), March (Mowlid), April (Easter), the end of Ramadan and Arafa (the latter are Islamic festivals that move forward each year.

Other important economic activities include the sale of trees, firewood and local brewing. Firewood is transported to local markets by donkeys, mainly by women and girls from very poor and poor households. Trees are sold once in every three years by men. Sale of firewood is done from January to March. Brewing is done throughout the year. There is credit facility to support the livelihood of very poor and poor households. This credit facility ranges from Birr 500 – 1500. The interest rate is

10.5%. The repayment period for this credit is one year. Very poor and poor households use this credit to purchase oxen and engage in petty trading activities.

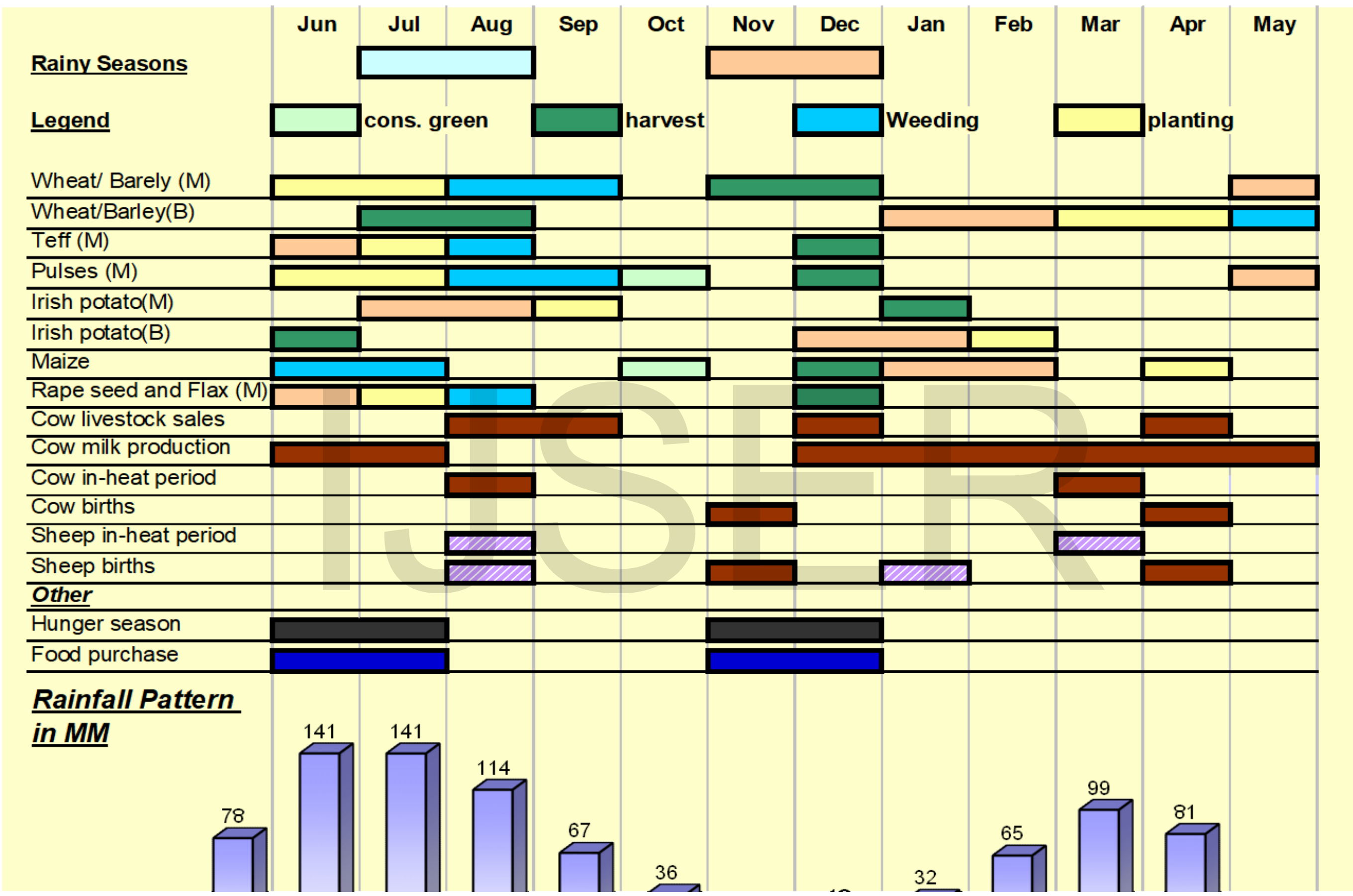

Figure 2 Livelihood Calendar for the study area

With regards to labor, 100% of the casual labor performed by people is in local rural area, with limited access to market.There is also labor migration into the livelihood zone in the months of December, January and August to do agricultural activities.

Ginir and Gololcha are also found in Agarfa, Gasera, Ginir and Gololcha Fruit, Coffee & Chat (AFC) Livelihood Zone located in Shirka, Robe and Seru woredas of Arsi and Ginir, Gassera, Gololcha and Agarfa woredas of the Bale zone. The livelihood zone is predominantly lowland or *kola* though some parts are midland or *woinadega*. The major category of livelihoods is mixed farming, mainly crop and livestock production. The main types of crops grown are maize, teff, sorghum and wheat and horticultural crops such as sugar cane, bananas, chat, oranges and coffee. Livestock such as cattle, goats and donkeys are also reared to support the livelihoods of the people. Chickens and beehives are other activities that generate income. Valleys, gorges and rugged terrain dominate the zone. The vegetation coverage includes bush and indigenous trees such as acacia and juniper. The main rivers are Wabe, Weyib, Inzara and Melka Qore rivers. The main towns are Gobessa, Ginir, Jara, Gassera, Agarfa and Robe. The asphalt road that comes from Addis Ababa connects Assela and Bale towns passing through the zone.

3.1.1 Climate and Agro- Ecology

The climate of the study area is characterized mainly by humid, warm and dry climate with relatively moderate precipitation. Weather conditions of the districts are classified under, Highland, Midland and Lowland of ecological zone. The altitude range of Sinana, Ginir, Goro and Gololcha woredas was from 1650 to 2400, 1360 to 2400, 1360 to 1800 and 700 to 2300 meters above sea level respectively.. The average annual rainfall in Sinana, Giniri, Goro and Golocha are 1060 to 1150 mm ,200 to 1200mm, 630 to 1150mm, 700 to 2300mm, respectively. The average annual temperatures is 9^0C to 23^0C,23^0C to 27.7C^0, 12 to 35C^0, and 18 to 30C^0 respectively. Sinana, Ginir, Goro and Gololcha districts are characterized by receiving bi-modal type of rain fall in two seasons, namely Belg and Meher. The Belg season falls between Mid-March and first week of June while, the Meher season is between mid- July and Mid-November (BZDPPOEWB, 2013).

3.1.2 Topography and Vegetation

The area is endowed with rich natural resources such as forest, wild life, and water, but degrading at alarming rate due to the increasing human interference which is attributed to the increasing population pressure and improper natural resource management. Topography is slightly undulating or rolling land with hill and mountains especially in the highlands and almost flat in the lowlands areas (BZFEDO,2013).

3.1.3 Production System

Agriculture is the main livelihood of the population and characterized by subsistence mixed farming system or crop and livestock. Major crops grow in the highland and midlands of Sinana, Ginir, Goro and Gololcha includes Wheat, Barley, Maize, F. Beans, pea and oil crops while, maize, sorghum and Teff are the dominant crops grown in the lowland areas of the woredas and spice crops are grown as cash crops in Goro woreda. Shortage and uneven distribution of rainfall affects the livelihood of the lowland peoples of the Districts. Of the study area, three Districts are the most vulnerable to chronically food insecure, and categorized as one of the food in secured area of the zone. Hence, the districts are dominated by dry climatic condition in lowland areas. As a result, scarcity of food, water and pasture is experienced to be the main problem the study areas (BZDPPOEWB, 2013).

3.1.4 **Soil Types**

The dominant soils type in Sinana, Ginir, Goro and Gololcha districts are verity soil, black soil, clay soil, and sandy soils. While the soils on the slopes have no drainage problem, those in valley bottoms are with poor drainage. As a result, water logging during the rainy season is experienced in the highland areas (BZFEDO, 2013).

3.1.5 Population

Based on 2000 E.C. population and housing census of Ethiopia the projected population size of Sinana, Ginir, Goro and Gololcha woredas were 131,704,145,262, 103,827 and 104,047 respectively. The average family size of the rural population of the areas is about six to eight persons per house hold and the average population density of the region is 53 to 60 persons per square km^2. Almost majority of the inhabitants are Oromo. Muslims population is estimated to be around 75 % while the remaining percentages are different Christian's religion and traditional religion of believing in one God (wakefata) (BZFEDO, 2013).

3.1.6 **Sampling Design**

For this study, four Districts were chosen purposively to represent the three agro-ecological zones of Bale zone (highland, midland and lowland). Data collection tools include Semi-structured interviews, focused group discussions, key informant interviews and secondary data reviews. A proportional sample size of between 36 and 62 households were selected from each district randomly to give a total sample size of 200 households. The selection of the households from some peasant associations (kebeles) of each District put into account that most of the kebeles they come from represents the District in biophysical, agricultural and socio-economic aspects. Most importantly, the kebeles had selected so that they represent the main farming practices, crop varieties, socio-economic status, climate problems and disasters besides topographic features of each District. But in case of random selection, we can use sample size calculation formula using Yamane (1967).

$$n = \frac{N}{(1+N(e)^2)}$$

Where n is the sample size, N is the population size, and e is the desired precision.

Now, considering the projected rural population of Ginir, Goro, Gololcha and Sinana we found as Ginir=145,262 **(**22114 HHs); Rural population of Gololcha=104047 **(**17010 HHs), Rural population of Goro= 103,824 (12840 HHs**)** and rural population of Sinana= 131,704(19635), the total population of the four sample woredas was found to be N= 484,837 (71,599) and the total HH population was 71,599.

If we allow a precession of 7.05 %(if we allow possible deviation of 7.05% from the true value), i.e. e=7.05%=0.0705, then the sample size required n= (71,599/ (1+71,599x0.0705^2) =200…Using household population in the formula. The same answer was obtained when using total population in the formula.

Thus, a total of 200 households have been selected from the four Districts. Further, considering proportional allocation of samples, probability proportional to population size was used to allocate the 200 sample HHs to the four Districts. Accordingly, using PPS (probability proportional to size), 62 households from Ginir, 47 households from Gololcha and 36 households from Goro and 55 households from Sinana were included in the household interview for analysis.

Due to the practical difficulties in the administration of Simple Random Sampling to districts,cluster random sampling was adopted .i.e. after calculating the cluster size (number of households a team can visit per day, say 7HHs/day) then a cluster size was found to be 7.Thus, dividing the households to be sampled from each District by 7, we get number of clusters to be visited from each district. Accordingly,62/7=8 clusters from Ginir, 47/7=6 clusters from Gololcha, 36/7=5 cluster from Goro and 55/7=7 clusters from Sinana. Now, considering PAs as cluster as a Cluster, then 8 Kebeles from Ginir; 6 Kebeles from Gololcha, 5 Kebeles from Goro, 7 kebeles from Sinana were visited randomly. After the PAs were chosen randomly then 7 households were selected from the selected PAs randomly.

3.2 Model and Variables Description

3.2.1 Dependent Variable

The consistent of most Ricardian models that have been developed in the literature, the dependent variable in the Ricardian model is per hectare agricultural land values or net revenue. Net revenue or land value can be used to represent farm income. Mendelssohn et al. (1994) used both net revenue and land value, whereas Polsky and Esterling (2001), used only land value as the dependent variable in their studies of the impact of climate change on the United State's agriculture. This study also use net revenue as dependent variable.

3.2.2 Independent Variable

In the Ricardian model developed for this research, the independent variables are categorized into two groups: Climate and Non-Climate variables. For non-climate factors, a variety of social and economic factors are included in the model. Moreover, Population density (people per km^2), per capita income, farm size, expenditure with farm activities, average income in each household, socio-demographic variables, technological variables and adaptation related variables are specified for non-climate factors. For Climate variable temperature and precipitation are considered as independent variables.

3.2.3 Data Collection

A cross-sectional study employing different ways of data collection methods was applied to collect data using primary data collection tools like household surveys, FGDs, key informant Interviews and secondary data from relevant sectors. Climate data was collected from different Global open sources like Africa Rainfall and Temperature Evaluation System (ARTES) and soil data from FAO. Moreover, climate data was also collected from NMA. Attempts were made to adjust the Global as well as National level climate data to district level using dawn scaling mechanism. Thin plates spline method of spatial interpolation was used to impute Household –specific rainfall and temperature values using latitude, longitude and elevation information of each household (Wahba, 1990; Hong et al., 2005).

For the future prediction, the climate change scenario data used for this study was based on simulations carried out using General Circulation Models (GCMs) for the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007).Data from Canadian Climate Center had also been used for the future prediction. For assessment we used simulations of monthly temperature and precipitation over the period 1901-2100 carried using the climate models and HADCM3. The raw data was downloaded from the website of IPCC Data Distribution Centre. Data on soil had obtained from Zonal Agriculture Office or from the Food and Agricultural Organization digital soil map of the world (FAO, 2003) which could be extrapolated to district level using Geographical Information System. Hydrology data on flow and runoff for each district was sought from Bureau of Water, Mineral and Energy of the region or from Global open sources to be modeled to the district using hydrological models for Africa.

To assess the impact of climate change on agriculture, a primary data was collected from small holder farming households across the zone purposively from four districts representing Highland, Mid-land and Lowland. Again, from each district, 50 households within the same agro ecology were selected randomly. Specific data was collected on different agricultural activities like farm size, gross income from agriculture for a period of one production year retrospectively. Expenditures related with farm activities and then net revenue per hectare for that household was calculated. Moreover, data was collected on soil type, mean monthly as well as seasonal (for the four seasons) temperature at district level, mean monthly as well as seasonal (for the four seasons) rainfall at district level, mean revenue per hectare at district level, socio-economic variables like household size, distance to input market and level of education of the head of the household were collected.

3.3 Data Analysis

Using Ricardian approach, net farm revenue were regressed against various climate, soil, hydrological and socio-economic variables to help determine the factors that influence variability in net farm revenues using IMB version 20. Moreover, the marginal impact analysis was conducted to observe the effect of an infinitesimal change in temperature and rainfall on the agricultural farming of the study area. Ricardian method is a cross-sectional approach to studying agricultural production. It was named after David Ricardo (1772–1823) because of his original observation that the value of land would reflect its net productivity. Farmland net revenues (V) reflect net productivity. This principle is captured in the following equation:

$V = \Sigma Pi\, Qi\, (X, F, H, Z, G) - \Sigma Px\, X$ ………………………………………………….. (1)

Where *Pi* is the market price of crop i, *Qi* is the output of crop i, *X* is a vector of purchased inputs (other than land), *F* is a vector of climate variables, *H* is water flow, *Z* is a vector of soil variables, *G* is a vector of economic variables such as market access and *Px* is a vector of input prices (see Mendelsohn et al., 1994). The farmer is assumed to choose *X* to maximize net revenues given the characteristics of the farm and market prices. The Ricardian model is a reduced form model that examines how several exogenous variables, *F*, *H*, *Z* and *G*, affect net revenues.

The standard Ricardian model relies on a quadratic formulation of climate:

$V = B0 + B_1F + B_2 F^2 + B_3H + B_4 Z + B_5 G + u$……………………………………… (2)

Where *u* is an error term. Both a linear and a quadratic term for temperature and precipitation are introduced. The expected marginal impact of a single climate variable on farm net revenue evaluated at the mean is:

E [dV/dfi] = b1, i + 2*b2, i *E[fi]-…………………………………………………………….. (3)

The quadratic term reflects the nonlinear shape of the net revenue of the climate response function (equation 2). When the quadratic term is positive, the net revenue function is U-shaped and when the quadratic term is negative, the function is hill-shaped. We expect, based on agronomic research and previous cross-sectional analyses, that farm value will have a hill-shaped relationship with temperature. For each crop, there is a known temperature at which that crop grows best across the seasons. The relationship of seasonal climate variables, however, is more complex and may include a mixture of positive and negative coefficients across seasons. The change in annual welfare, ΔU, resulting from a climate change from C_0 to C_1 can be measured as follows.

$\Delta U = V(C_1) - V(C_0)$ ………………………………………………………………… *(4)*

The impact of climate change on the net revenue per hectare is analyzed using different climate change scenarios like the uniformly scenarios and SRES climate scenarios with predicted values of temperature and rainfall from HaDCM3. Other forms of descriptive statistics was made on different variables like socio-demographic characteristics

4 RESULT AND DISCUSSIONS

4.1 Regression Results

4.1.1 Data and empirical analyses

The data for this study was collected from four districts of Bale zone namely Ginir, Goro, Gololcha and Sinana. In the zone, the districts were chosen to get a wide representation of farms across climate conditions in that zone. The districts might not be fair representative of the distribution of farms in the zone as there might be more farms in more productive locations. In each chosen district, a survey was conducted of randomly selected household farms. The sampling was clustered in villages to reduce sampling costs.

A total of 200 households were surveyed from the study area. The number of surveys across districts varied depending on the household population of the district while Probability proportional to population size (PPS) is applied. Not all the surveys could be used. Some farms did not grow crops (they only raised livestock). Some surveys contained incorrect information about the size of the farm, cropping area or some of the farm operating costs. Impossible values were treated as missing values. It is not clear what the sources of these errors were but field and measurement errors are most likely. They may reflect a misunderstanding of the units of measurement, they may reflect a language barrier, or they may be intentional incorrect answers. The final number of useable surveys was 196 for some variables and 200 for others and their distribution by district is shown in Table 1.

Table 1 Cluster and sample allocation to the surveyed districts

District	No.PA visited	No.HHs visited per PA
Ginir	9	62
Gololcha	7	47
Goro	5	36
Sinana	8	55
Total	29	200

Temperature and precipitation data were obtained from the Sub Office of the National Meteorological Agency

(NMA) at Bale Robe. There are many ways one could represent monthly temperatures and precipitation data in a Ricardian regression model. It is not advisable to include every month, because there is a high correlation between adjacent months. Thus, we used the seasonal (winter, summer, spring and fall) climate data in the Ricardian model. Soil data was obtained from the zonal Agricultural Office and compared with the data obtained from Food and Agriculture Organization of the United Nations (FAO, 2003). The FAO data provides information about the major and minor soils in each location as well as slope and texture. It was not easy to obtain Hydrology data .Thus, flow and runoff for each district couldn't be included in the model. But, the zonal Water and Energy bureau mentioned that there is no as such significant difference in the flow and runoff of water among the study area and could be considered to be constant in the model with minimum contribution to the model specification. The study also focus on rain fed agricultural practice as irrigation is not practiced as such. Production inputs and outputs were collected for two cropping seasons-Meher (the long rainy season) and Belg (the short rainy season) at household plot level. Most of the respondents responded to exercise both seasons. Thus, land value for both seasons was calculated from the return of three major crops produced during meher and from three major crops produced for Belg season. Then, gross income per hectare from both seasons was calculated and finally average annual gross revenue per hectare was calculated.

Detailed data on cost of production were collected at different production stages at plot level: land preparation, planting, weeding, harvesting and post-harvesting processing. Labor inputs were disaggregated as adult male, adult female and children and OECD/EU standard conversion factor was used to calculate per hectare labor input.Net revenue was calculated as gross revenue minus the costs of hired labor including for packaging and marketing (valued at the median market wage rate), fertilizer and pesticide. The median prices at locality were used to value both crops and inputs whenever possible. We excluded household labor in the definition of net revenue because including it would lead too many households to having negative net revenues. This was the case whether we used the payments each household alleged it gave to household workers or whether we assigned market wage rates to household labor. The inclusion of household labor in net revenues is problematic, as reported in the agricultural development literature (Bardhan and Udry, 1999). We therefore defined net revenues without household labor costs and controlled for the effect of household labor by including household size as an independent variable.

Table 2 Maximum Temperature (O^c)(sample mean) of the sample districts-Observed (1985-2010)

District	Winter	Spring	Summer	Fall	Mean annual
Ginir	25.4	23.75	24.2	23.58	**24.2325**
Gololcha	26.76	24.93	23.84	23.33	**24.715**
Goro	29.49	27.5	27.74	27.03	**27.94**
Sinana	23.38	22.24	22.9	20.67	**22.2975**
Mean	**26.2575**	**24.605**	**24.67**	**23.6525**	**24.79625**

Table 3 Precipitation (mm) (sample mean) of sampled districts-Observed

District	Winter	Spring	Summer	Fall	Mean annual
Ginir	69.9	130.75	65.22	101.28	**91.7875**
Gololcha	37.9	87.4	104.0	22.2	**62.875**
Goro	57.82	118.56	61.13	98.62	**84.0325**
Sinana	39.5	85.38	112	46.09	**70.7425**
Mean	**51.28**	**105.5225**	**85.5875**	**67.0475**	**77.35938**

International Journal of Scientific & Engineering Research Volume 11, Issue 8, August-2020
ISSN 2229-5518

Table 4 Household/head characteristics (N=200)

Household characteristics	Sex	N	Percent (%)
sex of the household head	male	189	94.5
	female	11	5.5
	Total	200	100.0
marital status of the household head	married	190	95.0
	single	7	3.5
	divorce	1	.5
	widow	2	1.0
	Total	200	100.0
educational level of the household head	Literate	37	18.5
	Illiterate	163	81.5
	Total	200	100.0
Do you use chemical fertilizer?	yes	185	92.5
	no	15	7.5
	Total	200	100.0
did you use improved seed?	yes	111	55.5
	no	89	44.5
	Total	200	100.0
What is your soil type?	Highly fertile	12	6.0
	Moderately fertile	155	77.5
	Not fertile	33	16.5
	Total	200	100.0
is there agricultural extension service in your village?	yes	195	97.5
	no	5	2.5
	Total	200	100.0
is there farmer-to-farmer extension service	yes	183	92.0
	no	16	8.0
	Total	199	100.0
is there formal credit scheme?	yes	105	52.5
	no	95	47.5
	Total	200	100.0
Did you observed any change in climate?	yes	200	100.0
Have you ever exercised any form of adaptation to climate change?	yes	199	99.5
	no	1	.5
	Total	200	100.0

The survey instruments were designed to capture farmers' perceptions and understanding of Climate change as well as their approaches to adaptations. From the four districts, the farmers were asked about the trends of climate parameters of temperature and rainfall. Moreover, Appropriate statistical software's such as SPSS were used to analyze the data from the household socio-economic survey in order to underlying socio-economic variables determining the perception and traditional knowledge of the local communities on climate change and its impacts as well as their adaptation mechanism. As we see from the table 4 above, out of 200 households selected, 100% of households have perceived as climate is changing while the corresponding response majority of the household exercised any form of adaptation to climate change. Regarding to capture farmers' perceptions 92.5%, use of chemical fertilizer, 44.5%, use improved seed, 97.5%, use agricultural extension service in the village, 52%
,farmer-to-farmer extension service and 92% ,formal credit scheme sample households was perceive respectively responding to climate changes.

4.1.2 Climate factors and adaptations

Table 5 Climate factors in four Districts

	Minimum	Maximum	Mean	Std. Deviation
mean winter temperature	23.38	29.49	26.2601	2.22047
mean spring temperature	22.24	27.50	24.6066	1.92439
mean summer temperature	22.90	27.74	24.6658	1.83586
mean fall temperature	20.67	27.03	23.6509	2.25910
mean winter precipitation	37.90	69.90	51.2121	13.33139
mean spring precipitation	85.38	130.75	105.4305	19.66734
mean summer precipitation	61.13	112.00	85.6810	22.67448
mean fall precipitation	22.20	101.28	66.8198	34.13224

The Ricardian approach estimates the importance of climate and other variables on the capitalized value of farmland. Net revenue were regressed on climate and other control variables. A nonlinear (quadratic) model was chosen, as it is easy to interpret (Mendelssohn *et.al*., 1994). In the initial runs, the net revenue per hectare was regressed over the independent climate factors temperature and precipitation and their square terms for the four seasons. Table 4 and 6 shows the net revenue per hectare for the sample districts, averages of temperature, precipitation and the regression coefficients of the first run of net revenue over linear and quadratics terms of climate factors for the four seasons.

Table 6 Average net revenue per hectare in (ETB/ha) for the surveyed districts

District	Mean Net Revenue ETB/hect.	Minimum	Maximum	SD
Ginir	1366.07	-1731.67	10530.00	2312.12
Gololcha	10017.38	1995.00	21693.33	4637.61
Goro	5579.39	206.12	10308.00	2082.09
Sinana	5006.16	-320.80	19952.80	3794.49
Total	5492.25	-1731.67	21693.33	4550.69

Table 7 Average of climate factors used in the model

	Mean	Std. Deviation
net revenue per hectare without considering labor as expense	5515.3875	4530.96942
mean winter temperature	26.2601	2.22047
mean spring temperature	24.6066	1.92439
mean summer temperature	24.6658	1.83586
mean fall temperature	23.6509	2.25910
mean winter precipitation	51.2121	13.33139
mean spring precipitation	105.4305	19.66734
mean summer precipitation	85.6810	22.67448
mean fall precipitation	66.8198	34.13224
mean winter temperature squared	694.4957	117.74832
mean spring temperature squared	609.1717	96.10505
mean summer temperature squared	611.7543	93.70146
mean fall temperature squared	564.4410	108.30836
mean winter precipitation squared	2799.5011	1421.33348
mean spring precipitation squared	11500.4327	4206.70808
mean summer precipitation squared	7852.7499	3900.69936
mean fall precipitation squared	5623.9884	4399.15712

Table 8 Regression coefficients of climatic variables over net revenue per hectare

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	24035.328**	4469.577		5.378	.000	-15219.839	32850.817
mean spring temperature	1338.750**	171.284	.569	7.816	.000	1000.922	1676.579
mean winter precipitation squared	.818	.589	.257	1.390	.166	-.343	1.980
mean fall precipitation squared	-1.010**	.206	-.981	4.908	.000	-1.417	-.604

a. Dependent Variable: net revenue per hectare without considering labor as expense

Table 9 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.681[a]	.464	.456	3342.49938	.464	55.720	3	193	.000

a. Predictors: (Constant), mean fall precipitation squared, mean spring temperature , mean winter precipitation squared

Table 10 ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1867563735.324	3	622521245.108	55.720	.000[b]
	Residual	2156254311.602	193	11172302.133		
	Total	4023818046.925	196			

a. Dependent Variable: net revenue per hectare without considering labor as expense

As can be seen from table 9 above, of all the linear and quadratic terms of the climate factors for all seasons entered in to the regression model, only mean spring temperature, mean winter precipitation squared and mean fall precipitation squared were retained in the model while the rest were not significant and thus dropped from the model. For the three variables retained in the model, the model fit is found significant as can be seen from the ANOVA table.i.e., the hypothesis that all regression coefficients are zero is rejected and the alternative hypotheses that not all coefficients are zero is accepted ($p=0.000 < \alpha$ at 5% and 1%)) . Overall, the regression model explain 45.6 %(adjusted R^2) of the variation in net revenues from household farm to farm. When we test for the individual coefficients, coefficients of the spring temperature and the coefficient of fall precipitation square of the model are significantly different from zero.

Thus, when we consider only climate factors as explanatory variables of the response variable net revenue per hectare (NRPH) the model fit using only significant coefficients is given by:

$NRPH=24035.33+1338.75SpringTemp-1.01FallPrecipt^2$………………………………………. (5)

For a climate only model, a $1^{O}C$ increase in spring temperature will increase the net revenue per hectare by ETB 1338.75 and a 1 mm increase in the square of Fall Precipitation will decrease the net revenue per hectare by ETB 1.01.

In the second run of the regression model, a number of non climates (socio-demographic, agricultural inputs, etc.,) and all climate factors of linear and quadratic forms were considered in the regression model. Only few of the variables as seen in the coefficient table below were retained in the model as some of the variables were dropped due to their constant value detected(i.e., when all the respondents give same answer for the variable). Tables for Regression coefficients after including the climate and non climate independent variables to predict the net revenue per hectare.

Table 11 Model Summary

Model	R				Change Statistics					
		R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.707[a]	.500	.467	3314.46049	.500	15.257	12	183	.000	1.544

a. Predictors: (Constant), mean summer temperature squared, did you use improved seed?, sex of the household head, age of the household head, is there farmer-to-farmer extension service?, is there formal credit scheme?, weeding chemical used per hectare in ltrs, size of the household(hh population), what is your soil type?, is there agricultural extension service in your village?, altitude of the household location, mean fall temperature

b. Dependent Variable: net revenue per hectare without considering labor as expense

Table 12 ANOVA[a]

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	2011320370.247	12	167610030.854	15.257	.000[b]
Residual	2010373641.138	183	10985648.312		
Total	4021694011.385	195			

a. Dependent Variable: net revenue per hectare without considering labor as expense

b. Predictors: (Constant), mean summer temperature squared, did you use improved seed?, sex of the household head, age of the household head, is there farmer-to-farmer extension service?, is there formal credit scheme?, weeding chemical used per hectare in ltrs, size of the household(hh population), what is your soil type?, is there agricultural extension service in your village?, altitude of the household location, mean fall temperature.

Table 13 Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	60846.736	10745.342		5.663	.000
altitude of the household location	-13.636	2.333	-1.057	-5.844	.000
Did you use improved seed?	-1278.844	533.287	-.141	-2.398	.017
What is your soil type?	-1864.496	628.539	-.190	-2.966	.003
Is there farmer-to-farmer extension service?	513.919	1092.354	.031	.470	.639
Is there formal credit scheme?	-474.525	623.404	-.052	-.761	.448
weeding chemical used per hectare in ltrs	-1726.463	874.092	-.116	-1.975	.050
sex of the household head	1094.652	1069.962	.056	1.023	.308
age of the household head	-20.811	21.157	-.057	-.984	.327
size of the household(hh population)	164.433	99.702	.098	1.649	.101
is there agricultural extension service in your village?	134.693	1847.018	.005	.073	.942
mean fall temperature	810.259	423.354	.402	1.914	.057
mean summer temperature squared	-66.782	9.830	-1.371	-6.794	.000

The model summary shows that the variation in net revenue per hectare is explained at 46.7% by the explanatory variables, the ANOVA table shows that the model fit is significant .i.e. the null hypothesis which assume all coefficients were zero is rejected. There are some coefficients which are significantly different from zero to build the model. As we see from the t-test significance column of the table above, the coefficients for altitude of the household location, did you use improved seed, what is soil type, weeding chemical used per hectare in ltrs, marginally for mean fall temperature (and deliberately considered as it is a variable of interest for this research and its correlation with the response variable is significant) and mean summer temperature squared are significantly different from zero at 5%(0.05) significance level.

Finally, a reduced regression model is run by using those variables for which the coefficients are significantly different from zero (i.e., altitude, fall temperature, mean summer temperature squared, did you use improved seed, weeding chemical and soil type) as explanatory variables and the net revenue per hectare as response variable .Table below shows the model summary, ANOVA table and coefficients for the final reduced regression model.

Table 14 Descriptive Statistics

	Mean	Std. Deviation
net revenue per hectare without considering labor as expense	5515.3875	4530.96942
altitude of the household location	2070.03	353.151
Did you use improved seed?	1.45	.499
What is your soil type?	2.10	.463
weeding chemical used per hectare in ltrs	.5479	.30358
mean fall temperature	23.6509	2.25910
mean summer temperature squared	611.7543	93.70146

Table 15 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.697	.486	.470	3299.23987	.486	29.944	6	190	.000	1.512

a. Predictors: (Constant), mean summer temperature squared, did you use improved seed?, what is your soil type?, weeding chemical used per hectare in ltrs, altitude of the household location, mean fall temperature b. Dependent Variable: net revenue per hectare without considering labor as expense

Table 16 ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	1955671142.373	6	325945190.396	29.944	.000[b]
	Residual	2068146904.552	190	10884983.708		
	Total	4023818046.925	196			

a. Dependent Variable: net revenue per hectare without considering labor as expense
b. Predictors: (Constant), mean summer temperature squared, did you use improved seed?, what is your soil type?, weeding chemical used per hectare in ltrs, altitude of the household location, mean fall temperature

Table 17 Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	62392.005	9158.125		6.813	.000
altitude of the household location	-13.827	1.875	-1.078	-7.376	.000
Did you use improved seed?	-1185.136	524.841	-.131	-2.258	.025
What is your soil type?	-2020.736	612.867	-.206	-3.297	.001
weeding chemical used per hectare in ltrs	-1660.124	850.470	-.111	-1.952	.052

mean fall temperature	840.033	409.849	.419	2.050	.042
mean summer temperature squared	-67.422	9.324	-1.394	-7.231	.000

From the table above, again one can interpret that for a 1m unit increase in altitude, net revenue per hectare will decrease by ETB 13.83 ,when a farmer chooses not to use improved seed say moving from 1=use to 2=not use, there is a decrease in net revenue by about ETB 1185.14 i.e., a farmer that uses an improved seed was gain an average per hectare net revenue of ETB 1185.14 more than farmer who was not using an improved seed. Similarly, when a farmer shifts from soil type 1=highly fertile to soil type 2=moderately fertile or from moderately fertile to infertile, there Would be a decrease of Net revenue per hectare by about ETB 2020.74 and a farmer who use additional 1 liter of weeding chemical per hectare was lose a net revenue per hectare of ETB 1660.12 more than a farmer who didn't use additional weeding chemical. This suggests that proper care and consultation of experts is demanding to properly know advisable proportionate use of weeding chemicals per hectare. Similarly, 1^0C increase in mean fall temperature will increase the net revenue per hectare by ETB 840.03 and a 1^0C increase in the square of mean summer temperature will decrease the net revenue per hectare by ETB 67.42.Precipitation is found to be insignificant for this model. But, it has to be recalled that the square of fall precipitation was significant in the climate only mode discussed earlier.

4.2 Marginal Impact Analysis

The marginal impact analysis was undertaken to observe the effect of an infinitesimal change in temperature and rainfall in the study area. To see the marginal impact of the climate factors over the net revenue, we conducted the first order partial derivative of the final reduced model obtained from the coefficients obtained in table 18 above.

$NRPH=\beta_o+\beta_1 C+ \beta_2 C^2+ \beta 3NC+\varepsilon$ ………………………………………………………… (6)

Where β_o=the constant term of the model

β_1=coefficient of the linear term of climate

β_2=coefficient of the quadratic term of the climate variables

$\beta 3$=the coefficient of the non-climate variables

C= stands for climate variable

NC= stands for non-climate variables

NRPH=net revenue per hectare

ε = random term

Now, using the coefficients of table 18, the final model is given by,

NRPH=62392.005-13.827ALT-1185.136ImpSeed-2020.736SoilTyp-1660.124+840.033FalTemp-

$67.422 SumTemp^2$………………………………………………………… (7)

When we take the partial derivative 1 on the climate factors at their respective mean, we obtain:

E [dNRPH/dCi] = β_1i + 2* β_2i *E[Ci] ---where Ci is climate i,i=fall and summer in our model 7

Thus, the partial derivative of (4) will give us,

E [dNRPH/dfallTemp]=840.033 and

E [dNRPH/dsumTemp] =-67.422*2 E[SumTemp]=-67.422*2*24.67=-3326.64--------using the mean value of summer temperature from table 2.

Accordingly, increasing temperature marginally during the fall season will increase the net revenue per hectare by ETB 840.033 and increase in the square of summer temperature marginally reduces the net revenue per hectare by ETB 3326.64.This shows that increase in summer temperature affects the net revenue per hectare more profoundly.

4.2.1 Adaptation mechanisms to climate change by local farmers

The study was conducted in, Sinana, Ginir, Goro and Gololcha Districts of Bale zone, Oromiya Regional State South-east part of Ethiopia, particularly in four districts. Moreover, the ability to adapt climate change was good due to well awareness creation about climate change as well as their economic resources, because farmers depend on the rain fed agriculture system. The adaptation methods most commonly cited in the literature include the use of new crop varieties, crop diversification, mixed crop, livestock farming systems, early planting, activities, increased use of water and soil conservation techniques, and trees planted for shade and shelter (Mukheibir and Ziervogel, 2007). The results were similar to the findings that most of the farmers were done in response to climate changes. Moreover I couldn't use adaptation mechanisms in the model, due to constant variable.

4.3 Forecasts of climate impacts

4.3.1 Climate Change Scenarios

The climate change scenarios produced for this study were based on the outputs of GCM results that are established on the SRES emission scenarios. As the objective of this study was to get indicative future climate ensembles, the scenarios developed were only for maximum temperature, minimum temperature, and precipitation values. The outputs of HadCM3 GCM model for the A2 and B2 emission scenarios were used to produce the future scenarios. The SDSM downscaling model was adopted to downscale the global scale outputs of the HadCM3 model outputs into the local level. The future time scales from the year 2011 until 2099 were divided into three climate periods of 30 years and their respective changes were determined as deltas (for temperature) and as percentages (for precipitation) from the base period values.

4.3.2 Selection of General Circulation Model

Use of average outputs of different GCMs can minimize the uncertainties associated with each GCMs and can result in plausible future climates for impact studies. However, as this study was carried out within a very short period of time, only the HadCM3 model was selected for the impact study. Besides, HadCM3 was selected due to the availability of a downscaling model called statistical downscaling model (SDSM0 that is used to downscale the result of HadCM3 and CGCM1 models. However, the CGCM1 GCM currently does not have predictor files representing the study area window but only the North American Window. Consequently, all the data files used in this study were only for the HadCM3 GCM. The model results are available for the A2 and B2 scenarios, where A2 is referred as the medium-high emissions scenario and B2 as the medium-low emissions scenario. For two of these emission scenarios three ensemble members (a, b, and c) are available where each refer to a different initial point of climate perturbation along the control run. During this study data were available only for the “a” ensemble and hence only the A2a and B2a scenarios were considered.

HadCM3 is a coupled atmosphere-ocean GCM developed at the Hadley Centre of the United Kingdom’s National Meteorological Service that studies climate variability and change. It includes a complex model of land surface processes, including 23 land cover classifications; four layers of soil where temperature, freezing, and melting are tracked; and a detailed evapotranspiration function that depends on temperature, vapor pressure, vegetation type, and ambient carbon dioxide concentrations (Palmer *et al.,* 2004).

The atmospheric component of the model has 19 levels with a horizontal resolution of 2.5° latitude by 3.75° longitude, which produces a global grid of 96 x 73 cells. This is equivalent to a surface resolution of about 417 km x 278 km at the equator, reducing to 295 km x 278 km at 45° latitude. The oceanic component of the model has 20 levels with a horizontal resolution of 1.25° latitude by 1.25° longitude. HadCM3 has been run for over a thousand years, showing little drift in its surface climate. Its predictions for temperature change are average; and for precipitation increase are below average (IPCC, 2001).

4.3.3 Statistical Downscaling Model (SDSM)

Among the different approaches used for downscaling, the most common approach is the statistical downscaling method. As described by (Palmer *et al.,* 2004), this method is advantageous as it is easy to implement, and generation of the downscaled values involves observed historic daily data. The latter advantage ensures the maintenance of local spatial and temporal variability in generating realistic time series data. However, the method forces the future weather patterns to only those roughly similar to historic, which is its demerit. For this study, a model developed based on this statistical approach called SDSM was implemented.

The Statistical Downscaling Model 4.2.9 was supplied on behalf of the Environment Agency of England and Wales. It is a decision support tool used to asses local climate change impacts using a statistical downscaling technique. The tool facilitates the rapid development of multiple, low–cost, single–site scenarios of daily surface weather variables under current and future climate forcing (Wilby and Dawson, 2004). The software manages additional tasks of data quality control and transformation, predictor variable pre–screening, automatic model calibration, basic diagnostic testing, statistical analysis and graphing of climate data. The downscaling process is shown in figure 1.below. The bold boxes represent the main discrete processes of the model.

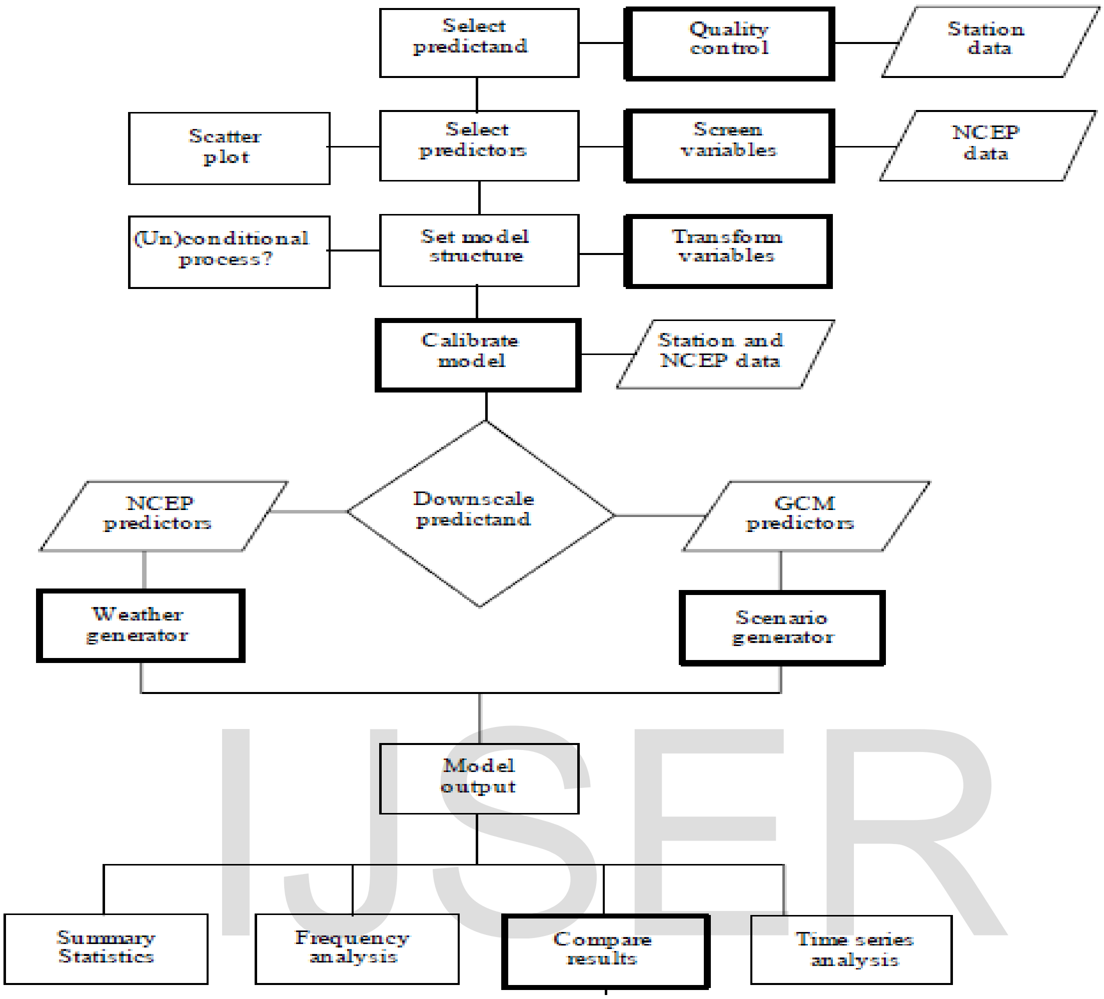

Figure 3 SDSM procedure

4.3.3.1 ***SDSM Model Inputs***

4.3.3.1.1 SDSM Predictors (HadCM3) Data Files

The SDSM predictor data files are downloaded from the Canadian Institute for Climate Studies (CICS) website http://www.cics.uvic.ca/scenarios/sdsm/select.cgi and the SDSM software was downloaded from open sourcehttps://co-public.lboro.ac.uk/cocwd/SDSM/software.html after getting registered on http://co-public.lboro.ac.uk/cocwd/SDSM/ . Even though there was a possibility of selecting predictors from different available GCMs like (HadCM3 and CGCM1), only the HadCM3 GCM has grid boxes representing the study area. CGCM1 model currently has predictor files only for the North American Window. Hence, the data files downloaded were only for the HadCM3 model. The predictor variables of HadCM3 are provided on a grid box by grid box basis of size 2.5° latitude x 3.75° longitude. As shown in figure 2, the study area completely

International Journal of Scientific & Engineering Research Volume 11, Issue 8, August-2020
ISSN 2229-5518

falls in between 6^{o}N to7.15^{0}‘‘N latitude and 40°E to 40.42°‘‘E longitude. Hence the nearest global grid box for the HadCM3 model (figure2), which represents the study area, is the one at 7.25°N latitude and 37.5°E longitude (Y=32 and X=12).

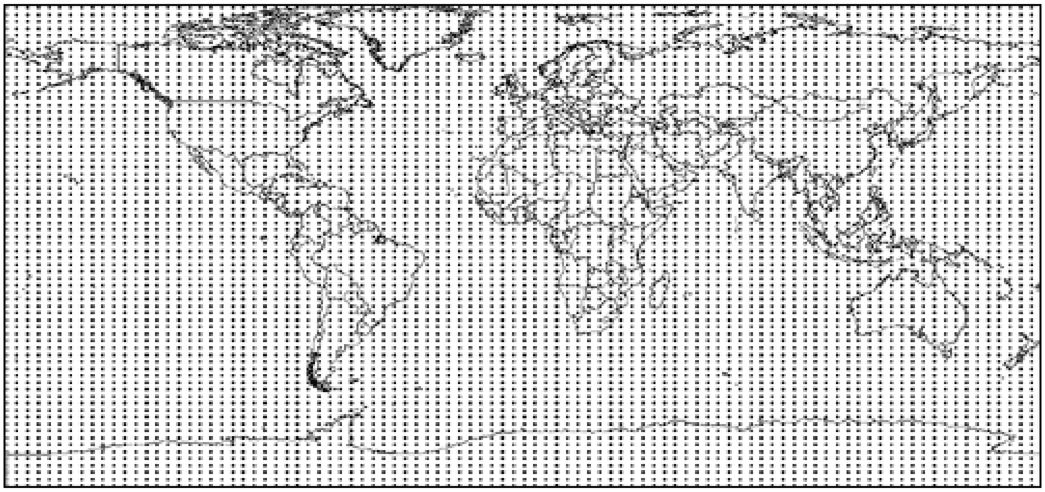

Figure 4 Global grid box

Once the X and Y coordinates for the study area was identified, we downloaded the HadCM3 data from the open source of CCCSN

ISSN 2229-5518

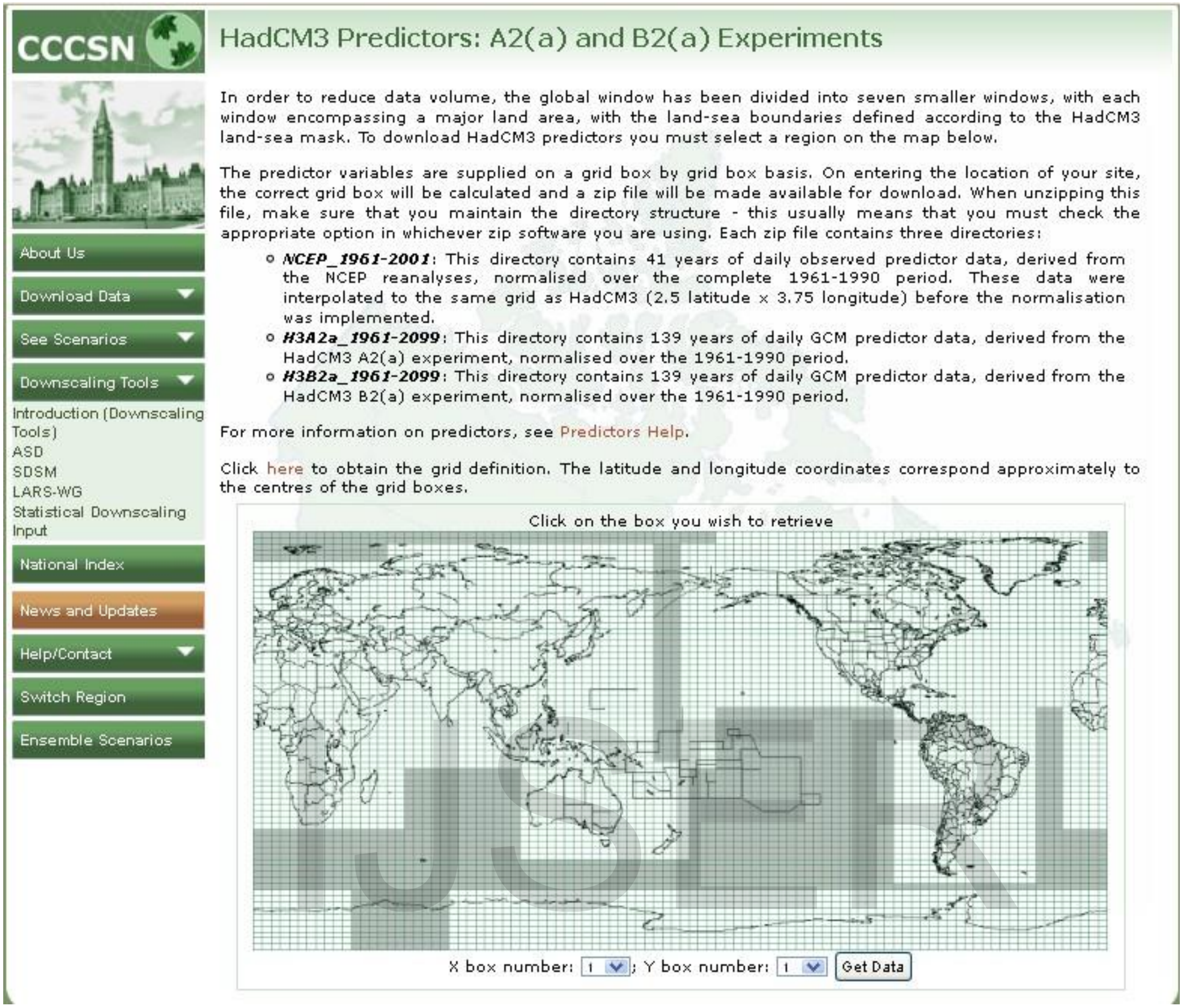

Figure 5 Web page of CCCSN to download predictors of the downscaling

Depending on the location of the station data, we choose the right box number and click on the ‘Get data’. For example, for Ginir station choose X=12 and Y=32 and click on Get Data.Authomatically, downloading of the zip file will start. Fortunately, all the stations in our study area fall in the same grid box. Thus, same GCM data was used for the downscaling procedure. When the downloaded zip file is unpacked, the grid box consists of three directories:

- NCEP_1961-2001: This contains 41 years of 26 daily observed predictor data, derived from the NCEP reanalysis, normalized over the complete 1961-1990 period.
- H3A2a_1961-2099: This contains 139 years of 26 daily GCM predictor data, derived from the HadCM3 A2 experiment, normalized over the 1961-1990 period.

- H3B2a_1961-2099: This contains 139 years of 26 daily GCM predictor data, derived from the HadCM3 B2 experiment, normalized over the 1961-1990 period.

NCEP data are re-analysis data sets from the National Centre for Environmental Prediction, which were re–gridded to conform to the grid system of HadCM3. These were the data used in the model calibration. Both the NCEP and HadCM3 data have daily predictor values (table19), which were used in the determination of the Predictands. According to (Wilby and Dawson, 2004), the predictors selected with regards to each predictand should be physically and conceptually sensible, strongly and consistently correlated with it, and accurately modeled by GCMs. Further it is recommended that for precipitation downscaling, the predictors should include variables describing atmospheric circulation, thickness, stability and moisture content.

Table 18 List of predictor variables in GCM

No	Predictor variable	Predictor description	No	Predictor variables	Predictor description
1	Mslpaf	Mean sea level pressure	14	P5zhaf	5000 hpa divergence
2	P_faf	Surface air flow strength	15	P8_faf	850 hpa airflow strength
3	P_uaf	Surface zonal velocity	16	P8-uaf	850 hpa zonal velocity
4	P_vaf	Surfacemeridional velocity	17	P8_vaf	850 hpa meridional velocity
5	P_zaf	Surface vorticity	18	P8_zaf	850 hpa vorticity
6	P_thaf	Surface wind direction	19	P850af	850 hpa geopotential height
7	P_zhaf	Surface divergence	20	P8thaf	850 hpa wind direction
8	P5_faf	500 hpa airflow strength	21	P8zhaf	850 hpa divergence
9	P5_uaf	500 hpa zonal velocity	22	P500af	Relative humidity at 500 hpa
10	P5_vaf	500 hpa meridional velocity	23	P850af	Relative humidity at 850 hpa
11	P5_zaf	500 hpa vorticity	24	Rhumaf	Near surface relative humidity
12	P500af	500 hpa geopotential height	25	Shumaf	Surface specific humidity
13	P5thaf	500 hpa wind direction	26	tempaf	Mean temperature at 2 m

4.3.3.1.2 Setting of model parameter

For the observed and the NCEP data the year length was set to be the default (366 days), which allows 29 days in February in leap years. However, for Scenario generation using predictor variables from HadCM3 which have modeled years that do only consist of 360 days, the default value was changed to 360 days. The base period used for the model was from 1/1/1986 to 31/12/2010.The event threshold value is important to treat trace values during the calibration period. For the parameter temperature, this value was set to be 0 while for daily precipitation calibration purpose this parameter was fixed to be 0.1 mm/day so that trace rain days below this threshold value will be considered as a dry day. Missing data were replaced by -999.

Model transformation is the other important part of the model, which specifies the method of transformation applied to the predict and in conditional models. For the daily temperature values, no transformation was used as it is normally distributed and its model is unconditional. However, for the daily precipitation, the fourth root transformation was used as its data are skewed and as its model is conditional. The range of variation of the downscaled daily weather parameters can be controlled by fixing the variance inflation. This parameter changes the variance by adding/reducing the amount of "white noise" applied to regression model estimates of the local process. The default value, which is 12 produces approximately normal variance inflation (prior to any transformation), and this was used for the daily temperature values; whereas for daily precipitation this value is set to be 18, in order to magnify the variation.

4.3.4 SDSM Model Approach

The processes that were undertaken to come up with the downscaled climate Parameters are the following:

4.3.4.1 Selection of Observed climate station data

Climate data was collected from four of the NMA stations found in the four districts. However, when data quality control was run by SDSM software, observed station data from Gololcha and Goro were found poor due to huge number of missing values. Thus, the statistical downscaling was done only at the remaining two stations of Ginir and Robe. Firstly, climate data used for downscaling (Rainfall and Temperature) from Ginir station was obtained from 1/1/1985 to 31/06/2014 and observed station data for Robe was obtained from 1/05/1980 to 31/07/2014 which are almost near to the required 30 years data for climate change study. The station data were obtained in excel format which couldn't be read directly by the SDSM software. Thus, the station data were first converted to ".dat" format to be read by the SDSM.

4.3.4.2 Quality Control and Data Transformation

The result of any model depends on the quality of the input data. Input data should, therefore, be checked for missing and unrealistic values in order to come up with good results. Besides, this function of SDSM provides the minimum, maximum, and mean of the input data. All the input data are checked for missing data codes and data errors before the calibration process.

4.3.4.3 Screening the downscaling predictor variables

The central concept behind any statistical downscaling method is the recognition of empirical relationships between the gridded predictors and single site Predict ands. This is the most challenging part of the work due to the temporal and spatial variation of the explanatory power of each predictor (Wilby and Dawson, 2004). The selection was done at most care as the behavior of the climate scenario completely depends on the type of the predictors selected. Annual analysis period was used which provides the predictor-predictand relationship all along the months of the year. The parameter which tests the significance of the predictor predictand relationship, significance level, was set to be equal to the default value ($p<0.05$). Moreover, the process type that identifies the presence of an intermediate process in the predictor-predictand relationship was defined.

For daily temperature, which is not regulated by an intermediate process, the unconditional process is selected. However, for daily precipitation, because of its dependence on other intermediate process like on the occurrences of humidity, cloud cover, and/or wet-days; the conditional process was selected. Several analyses were made by selecting 8 out of 26 predictor variables at a time till best predictor-predictand correlations were found checked by the p-values highly close to zero. Out of the group, those predictors which have high explained variance are selected. The partial correlation analysis is done for the selected predictors to see the level of correlation with each other. There could be a predictor with a high explained variance but it might be very highly correlated with another predictor. This means that it is difficult to tell that this predictor will add information to the process and therefore, it will be dropped from the list. Finally scatter plot was used to indicate whether the result is a potentially useful downscaling relationship.

4.3.4.4 Selection of Potential Predictor Variable

The first step in the downscaling procedure using SDSM was to establish the empirical relationships between the predictand variables (minimum temperature, maximum temperature, and precipitation) collected from stations and the predictor variables obtained from the NCEP re-analysis data for the current climate. That involved the identification of appropriate predictor variables that have strong correlation with the predictand variable. The next step was the application of these empirical predictor- predictand relationships of the observed climate to downscale ensembles of the same local variables for the future climate. Data supplied by the HadCM3 for the A2 and B2 emission scenarios for the period of 1961–2099 for both the stations were used. This was based on the assumption that the predictor-predictand relationships under the current condition remain valid under future climate conditions too. Therefore, according to the above procedure the potential predictors selected for maximum temperature, minimum temperature and precipitation for the study area were listed in table 20 below.

Table 19 Selected potential predictors for Ginir and Robe stations

Station	Predicant	Predictor	Symbol
GINIR	Max.Temp	Surface zonal velocity	ncepp-uaf.dat
		Surface divergence	ncepp-zhaf.dat
		500 hpa geopotential height	ncepp500af.dat
		850 hpa zonal velocity	ncepp8-uaf.dat
		Mean temperature at 2 m	nceptempaf.dat
	Min.Temp	Surface wind direction	Ncepp_thaf.dat
		500 hpa geopotential height	Ncepp500af.dat
		850 hpa geopotential height	Ncepp850af.dat
		Near surface relative humidity	Nceprhumaf.dat
			Nceptempaf.dat
		Mean temperature at 2 m	
	Precipitation	Mean sea level pressure	Mslpaf.dat
		Surface divergency	Pzhaf.dat
		850 hpa zonal velocity	P8faf.dat
		850 hpa vorticity	P8vaf.dat
		Relative humidity at 850 hpa	P850af.dat

4.3.4.5 **Model calibration**

This operation was normally carried out based on the outputs of the second step – selection of the predictor variables that uses the NCEP data base of the selected grid box. The mathematical relation between a specific predict and the selected predictor variables was estimated and the parameters of a multiple linear regression equation are determined. The temporal resolution of the downscaling model was selected by choosing the model type (monthly, seasonal, or yearly). In Monthly models, model parameters are estimated for each month of the year. Hence, for this study, the calibration was done for the period of 15 years (1986-2000) for both stations of Ginir and Robe at a monthly model type in order to see the monthly temporal variations. Still the processes selected as explained before are conditional for daily precipitation and non-conditional for daily temperature values.

4.3.4.6 Weather Generator and Validation

SDSM"s Weather Generator enables to produce synthetic current daily weather data based on inputs of the observed time series data and the multiple linear regression parameters produced during the calibration step. Each time-serious-data of the observed climate variable is linked to the regression model weights to generate the synthetic time series data into a serious of ensembles (runs). The results among the ensembles differ based on the relative significance of the deterministic and stochastic components of the regression models and mainly due to the stochastic component of the downscaling. As indicated in the SDSM manual, variables like local temperatures are largely determined by regional forcing whereas precipitation series display more "noise" arising from local factors. Hence, larger differences can be observed in precipitation ensemble members than that of temperature. The result of the weather generator was used to validate the calibrated model using independent observed data not used during the calibration procedure and the synthesized artificial weather time series data representing the present condition. Ten years of simulation from 2001-2010 was selected for the validation for both the stations.

4.3.4.7 Scenario Generation - Determination of the Impacted Climate Variables

SDSM has HadCM3 model output with the A2a and B2a SRES emission scenarios with grid boxes containing the study area. Hence for this study, the HadCM3A2a and HadCM3B2a were the two GCM output files used for the scenario generation. The regression weights produced during the calibration process were applied to the time series outputs of the GCM model. This is based on the assumption that the predictor-predictand relationships under the current condition remain valid under future climate conditions too. Twenty ensembles of synthetic daily time series data were produced for each of the two SRES scenarios for a period of 139 years (1961 to 2099). The final product of the SDSM downscaling method was then found by averaging the twenty independent stochastic GCM ensembles. The developers (Wilby and Downson, 2004) suggested that, as the target here is only to see the general trend of the climate change in the future; it is adequate to consider the average of the ensembles. They also added that to preserve inter-variable relationships, the ensemble mean should be used.

4.4 Climate change scenario results

4.4.1 Baseline scenarios

The base line scenarios downscaled for base period for the two stations; 25-year period from1985- 2010 was selected for both stations to represent baseline for this study. Thus the HadCM3 GCM was downscaled for the base period for two emission scenarios (A2a and B2a) and some of the statistical properties of the downscaled data were compared with observed data. In both stations the downscaled base line temperatures shows good agreement with observed data. In the case of precipitation, also even though there were little variations in individual months which are due to local effects, the downscaled values have good concurrence with observed data. In general, in both stations the downscaled climate variables (precipitations, maximum and minimum temperatures) have good fit with observed data as shown in the figure 6 to fig.8 which is very important for future climate generations.

4.4.2 Base line Scenario developed for period of 1985-2010

To downscale future climate it is necessary to use observed climate data, which is very imperative to calibrate and validate climate model. Thus HadCM3 was downscaled for the base period with two emission scenarios (A2a and B2a) and some of the statistical properties of the downscaled data were compared with observed data. The climatologically base line period used for the impact assessment was 1985-2010 for both stations. Precipitation, maximum and minimum temperature variables are also downscaled for future climate period (2011-2099).

4.4.2.1 Precipitation

The downscaled values of precipitation for the base period were averaged into a monthly time step to compare with observed values which are shown in figure 6 below. The SDSM model performs reasonably well in estimating the mean monthly precipitation in many months but there is a relatively large model error in the months of October, November, December and May. The result, however, can be taken as satisfactory given that precipitation downscaling is necessarily more problematic than temperature, because daily precipitation amounts at individual sites were relatively poorly resolved by regional scale predictors, rather it depends on local factors like topography.

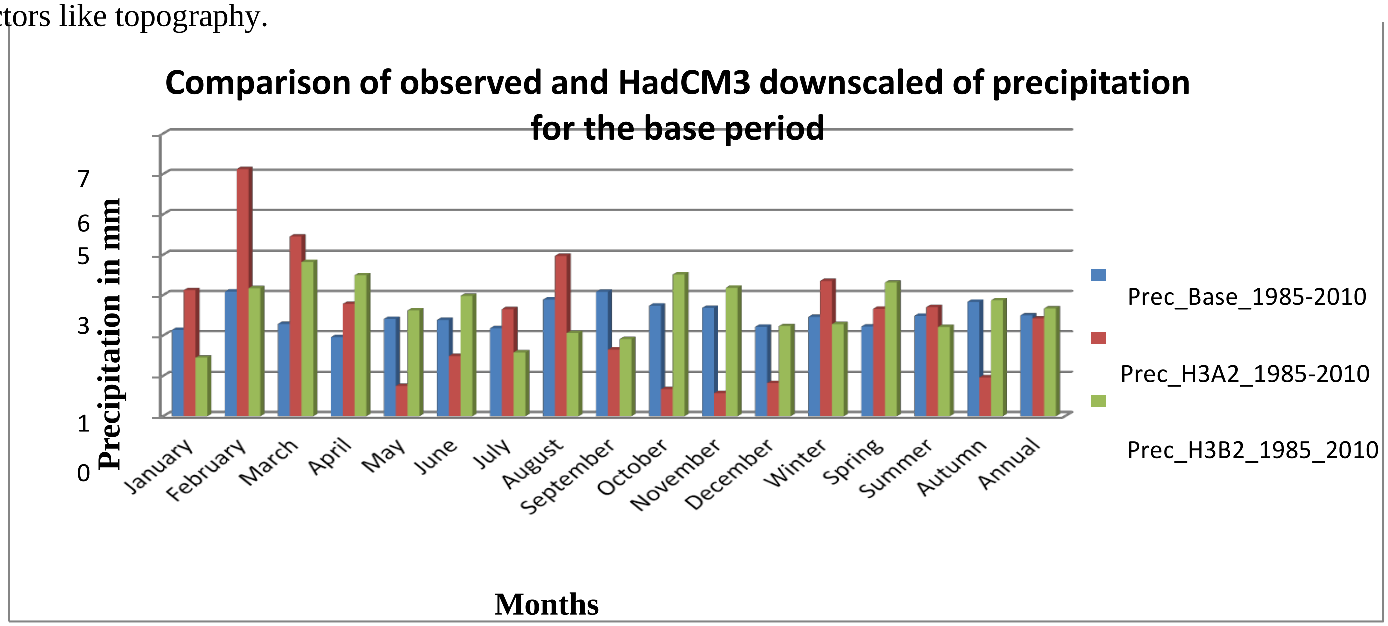

Figure 6 Average daily precipitations for Ginir station for base period

4.4.3 Maximum temperature

The projected maximum temperature for baseline period shows good agreement between observed and downscaled values Fig: 7 below. It shows maximum temperature on dry seasons fit with the observed data except for months of April, May, June and August where H3A2 scenario underestimates the current observed maximum temperature.

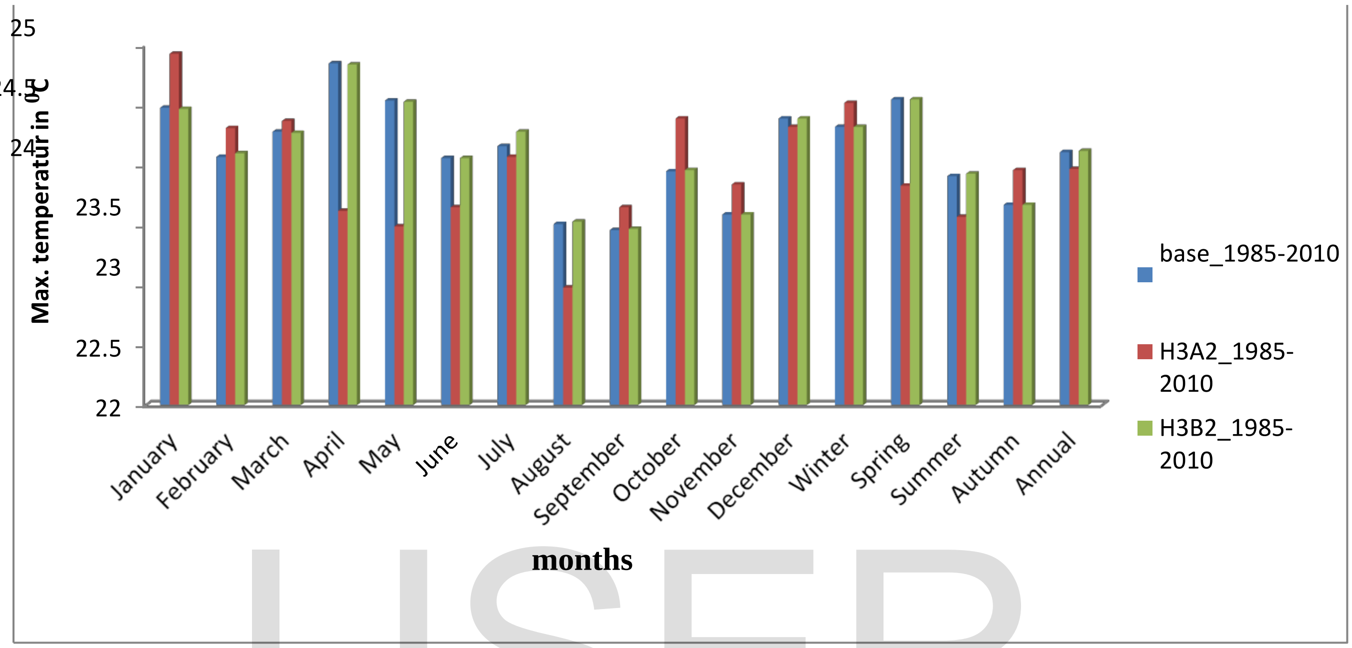

Figure 7 Average daily maximum temperature of observed and downscaled for the same period at Ginir station for base period

4.4.4 Minimum Temperature

Except little variation in months of October, November and December where the HadA2 scenario over estimated the base year minimum temperature at Ginir station, the model fit seem good for the rest of the months as indicated in fig. 8 below. In general the model output has similar trends with observed data which is satisfactory result for future projection of minimum temperature.

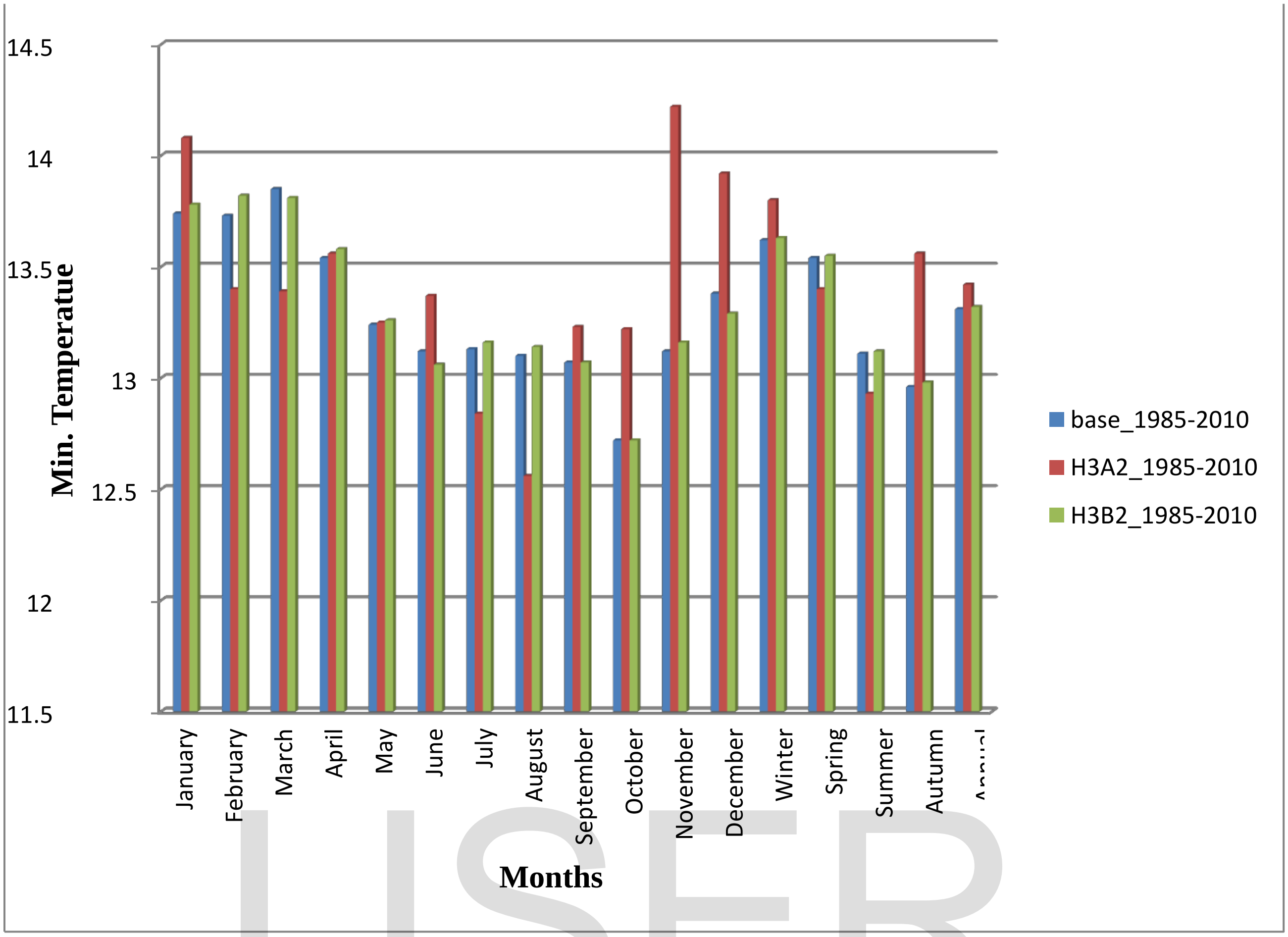

Figure 8 Observed and downscaled for the same period of Average daily minimum temperature of Ginir station for the base period

4.5 Downscaling future scenarios

Future climate scenarios downscaled for three climate variables (precipitation, maximum and minimum temperature) are shown in the figure 9 to13. With the aid of statistical downscaling model, the GCMs global predictors are used for development of future climate scenarios and the analysis done for 2020s, 2050s and 2080s for both A2 and B2 scenarios.

4.5.1 Precipitation

For Ginir station, the future rainfall projections show the decreasing trends for the months of May, June, September, October, November and December for all three periods by reproducing the actual patterns of precipitation for both A2 scenarios (Fig.9). As compared to the current situation (1985-2010), the 2020s, 2050s, and 2080s periods shows increasing for six months (Jan, Feb, March, April, July and August) and decreasing for the remaining six months as shown in figure 9 below. Whereas when individual months are considered, the 2020s period shows relatively dry condition during months of November. In general, in the future scenario, Autumn is going to be with less precipitation for all the three periods whereas the remaining season will be a bit wetter and the mean annual precipitation remain similar.

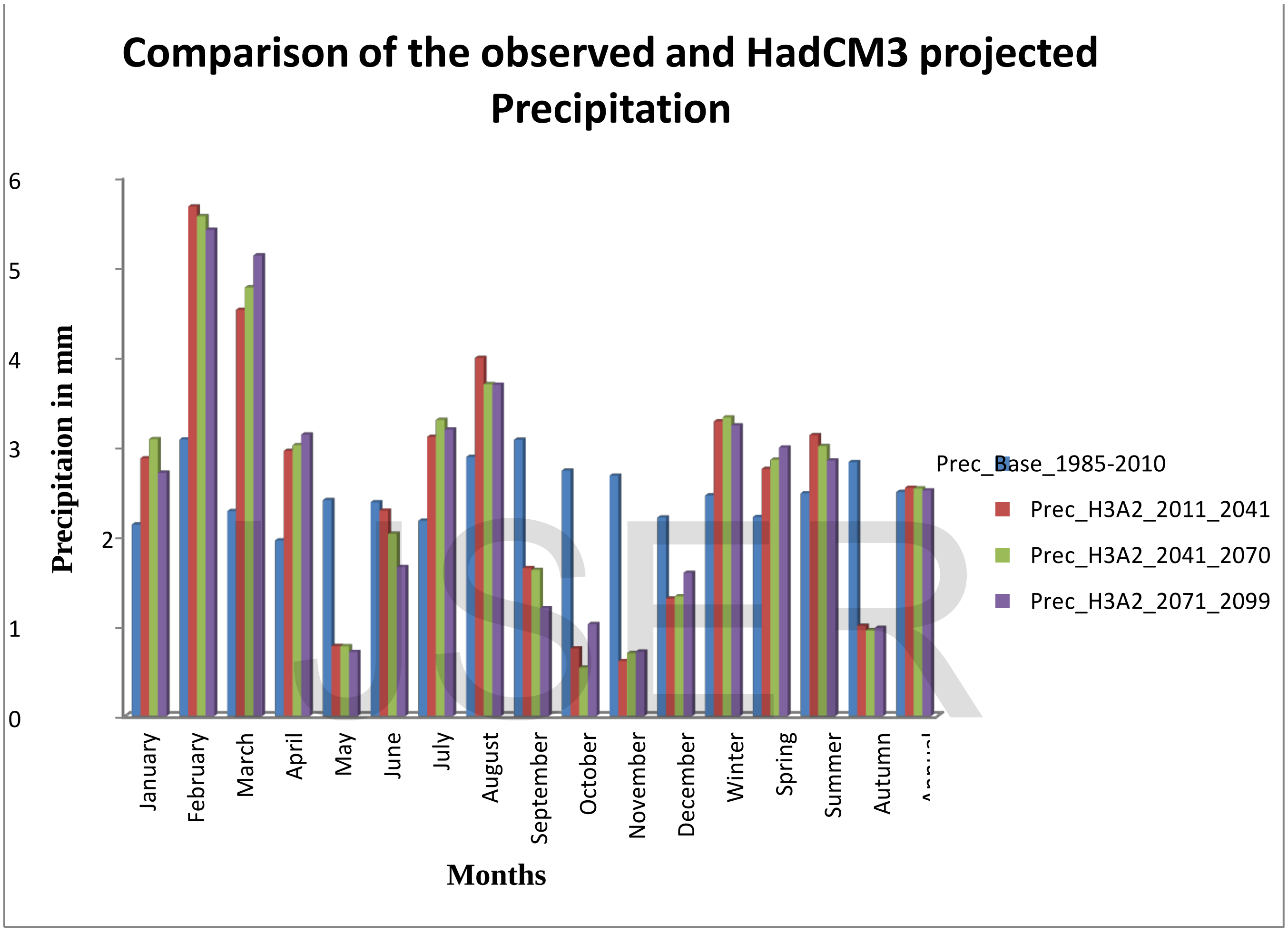

Figure 9 precipitation trend for the periods 2020, 2050 and 2080 for A2 scenario compared with the base year

Whereas for the B2a scenario, precipitation trend shows decrease only for the months of September, February and August and increasing for the remaining months as shown in fig.10 below. The result of this scenario seems in agreement with the projection of IPCC 2007 which predicts precipitation increase in highlands of East Africa for which Blae zone is the one. In general future projection of precipitation shows increase in all seasons except for winter and the maximum increase is expected in spring.

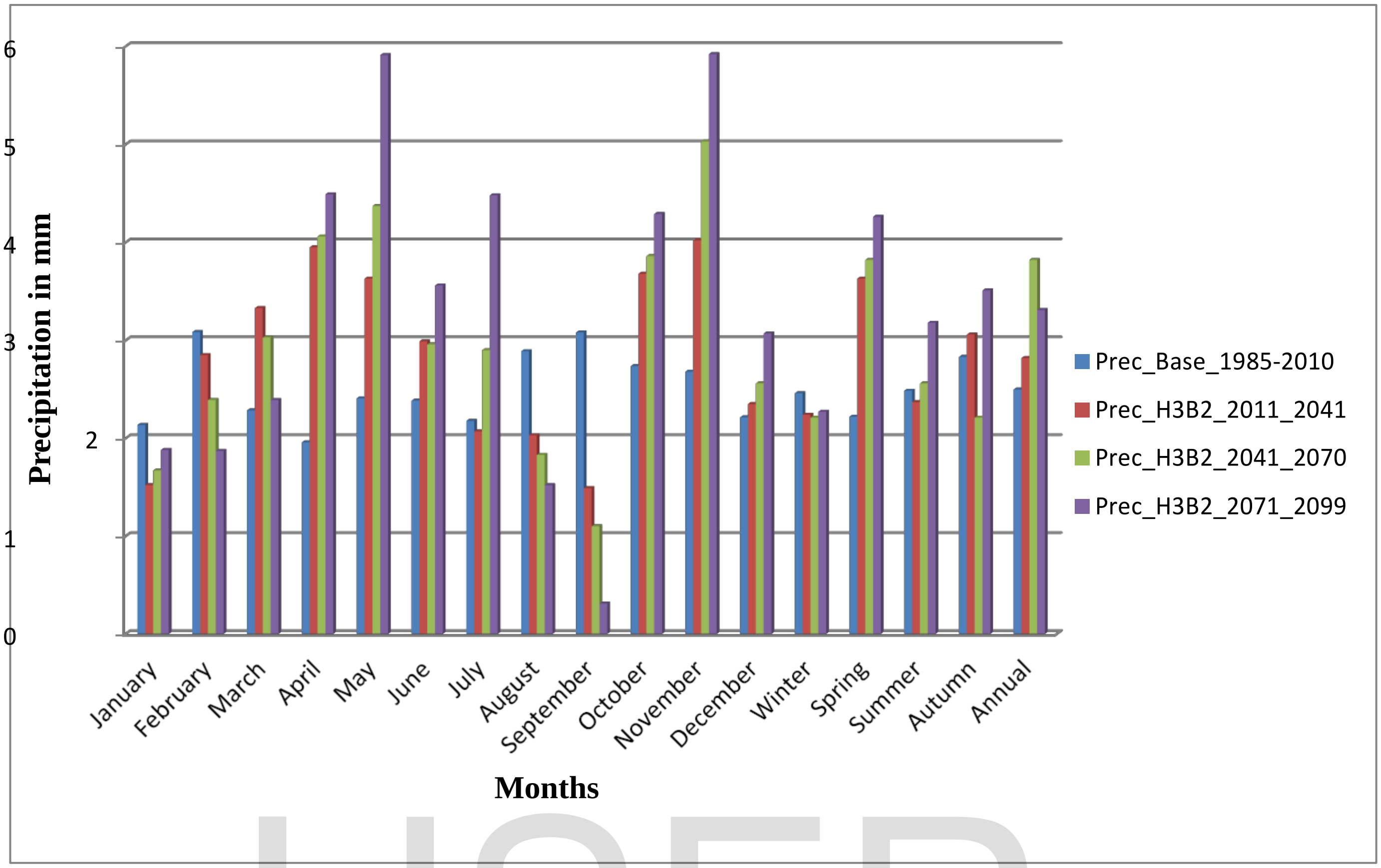

Figure 10 Precipitation trend for the periods 2020, 2050 and 2080 for B2 scenario compared with the base year

4.5.2 **Maximum Temperature**

Unlike that of precipitation, the projected maximum temperature shows similar trends and patterns for Ginir station which is increasing by 0.13^{o}c of the period 2080 trend for A2a but decreasing for the 2020 by 0.0860C and decreasing by 0.016 for the period 2050. For B2 scenario, maximum temperature decreased by 0.086^{o}c in 2020, increased by 0.176 in 2050 and increased by 0.297 in 2080 as shown in fig 11 and12 below. According to the IPCC (2001), potential climate changes in Africa would increase in global mean temperatures between 1.5^{0}C and 6^{0}C by 2100.

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ISSN 2229-5518

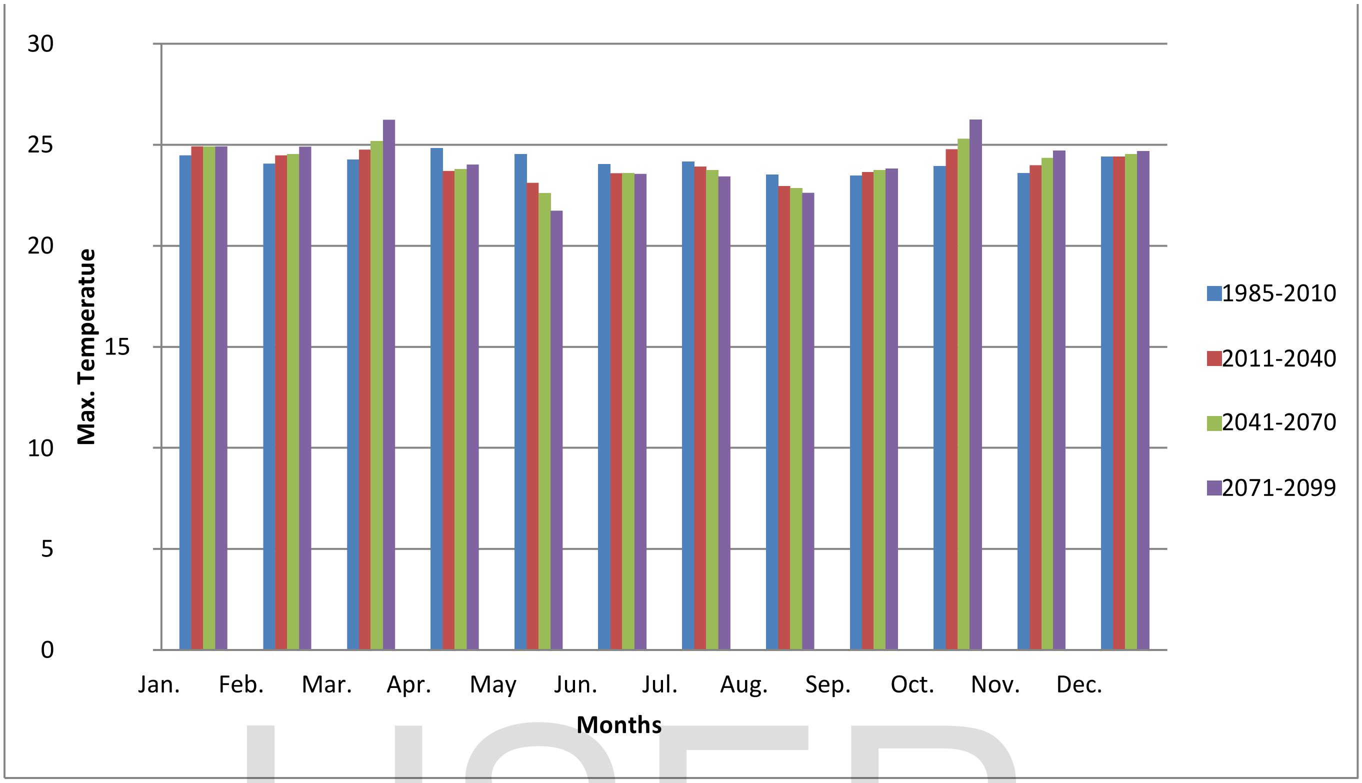

Figure 11 Observed compared with H3A2 scenario

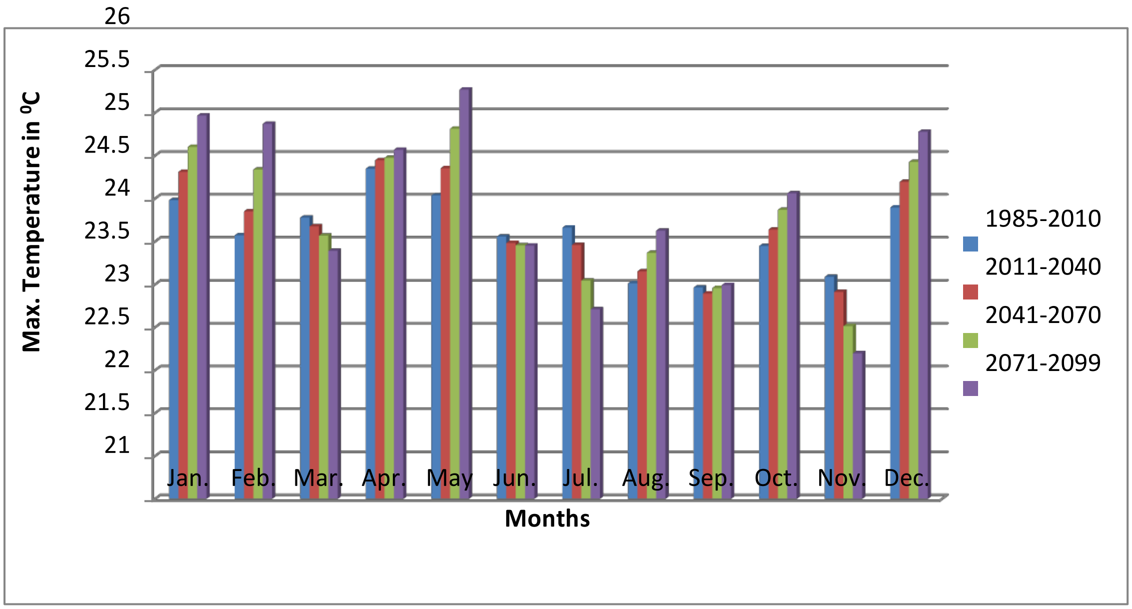

Figure 12 Observed compared with H3B2 scenario

4.5.3 Minimum Temperature

Like case of projected average monthly maximum temperature, minimum temperature also reflects increasing trend in future climate periods. The projected minimum temperature for future periods for A2a and B2a scenarios is shown in Figure fig 13 below. As change of minimum temperature for Ginir station shows similar future trends in minimum temperature, only Ginir station is discussed here for introduction as I didn't use minimum temperature in my regression model.

Even though all months show similar trends in the future climate periods, the highest maximum projected minimum temperature will occur during months of June and September, October and November for A2a and in July and October for B2a scenarios as shown in fig 13 and 14 below. The downscaled minimum temperature in 2020s indicated that the minimum temperature will rise by 0.15^{O}c for both A2a and 0.03^{O}c for B2 scenarios. For 2050s the increment will be 0.22^{0}C for A2a and 0.0^{0}C for B2a scenarios .For 2080, the minimum temperature increases by 0.34^{0}C for A2a and by 0.12^{0}C for B2 as indicated in trends given below

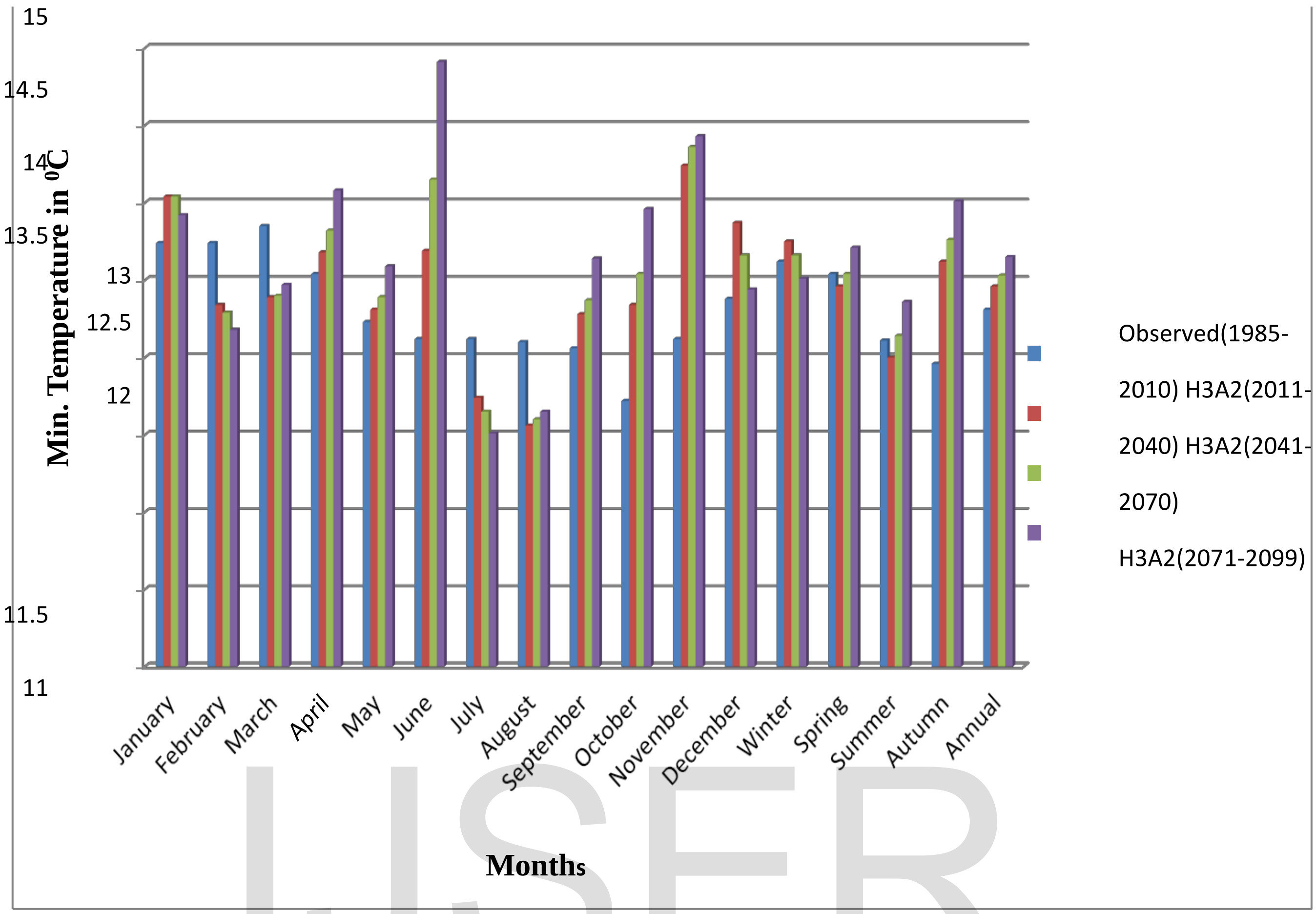

Figure 13 Trend in monthly minimum temperature of the base year and modeled result for future time at 2020, 2050 and 2080.

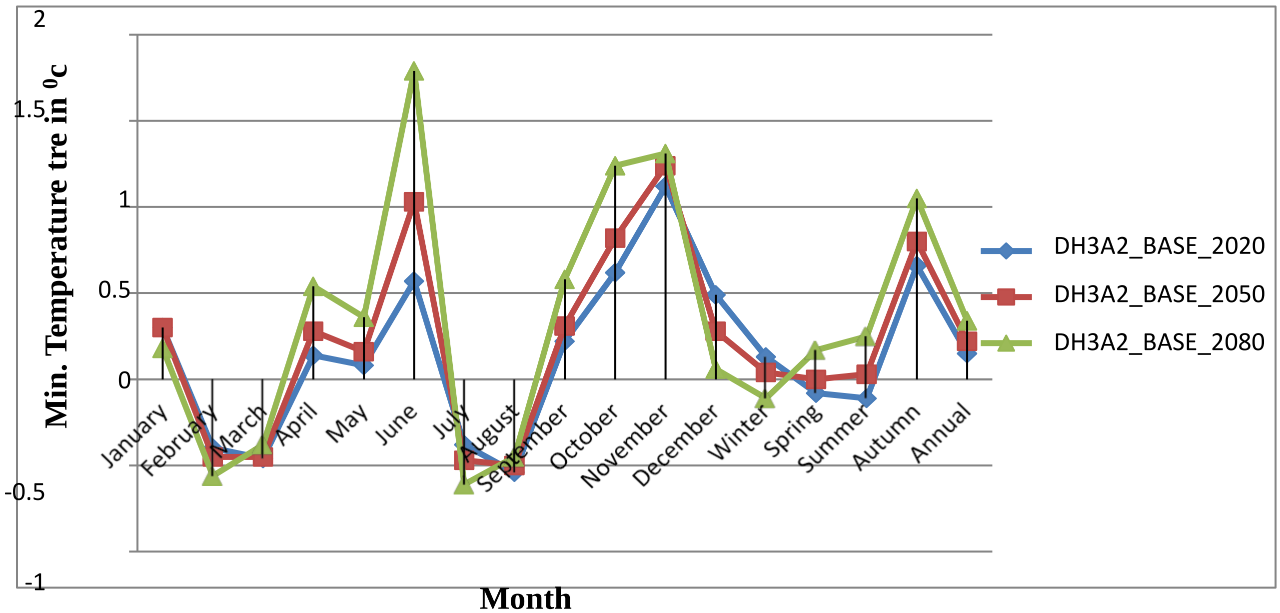

Figure14 Change (Delta) of the future minimum temperature of the H3A2 scenario when compared With the base period

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ISSN 2229-5518

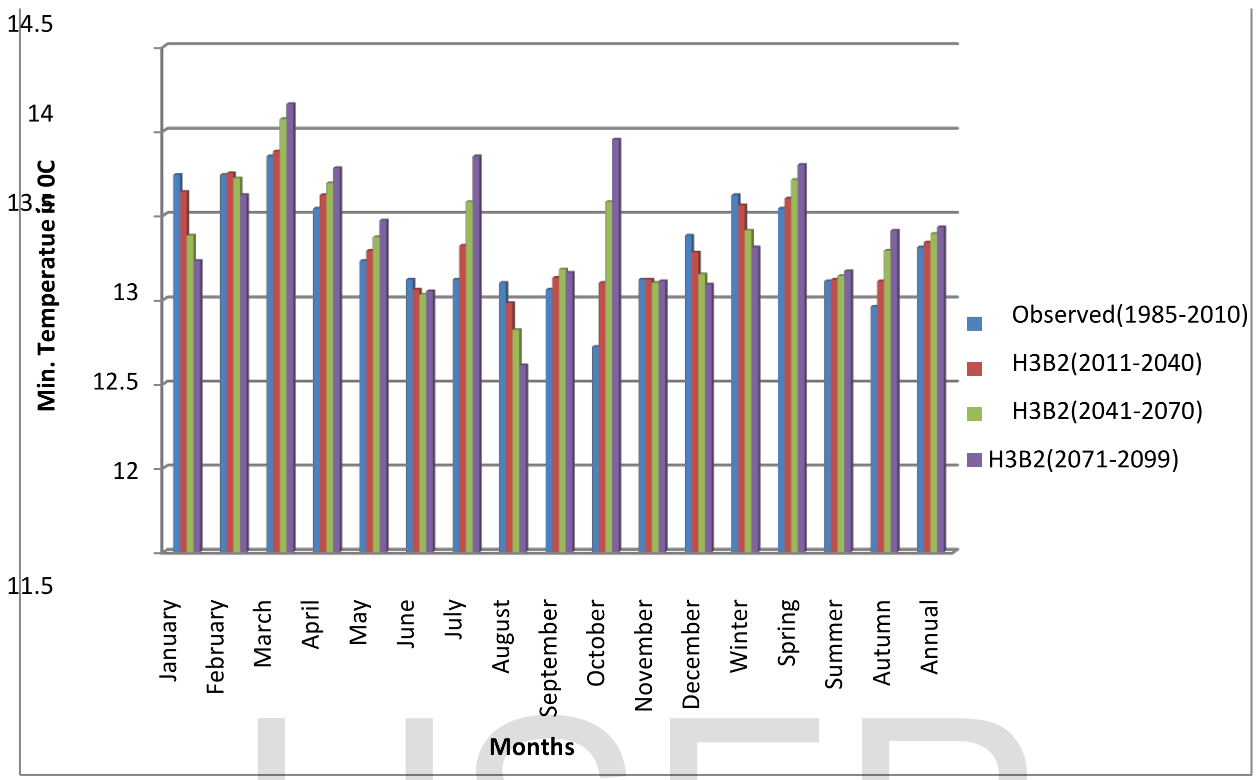

Figure 15 Trend in monthly minimum temperature of the base year and modeled result for future time at 2020, 2050 and 2080

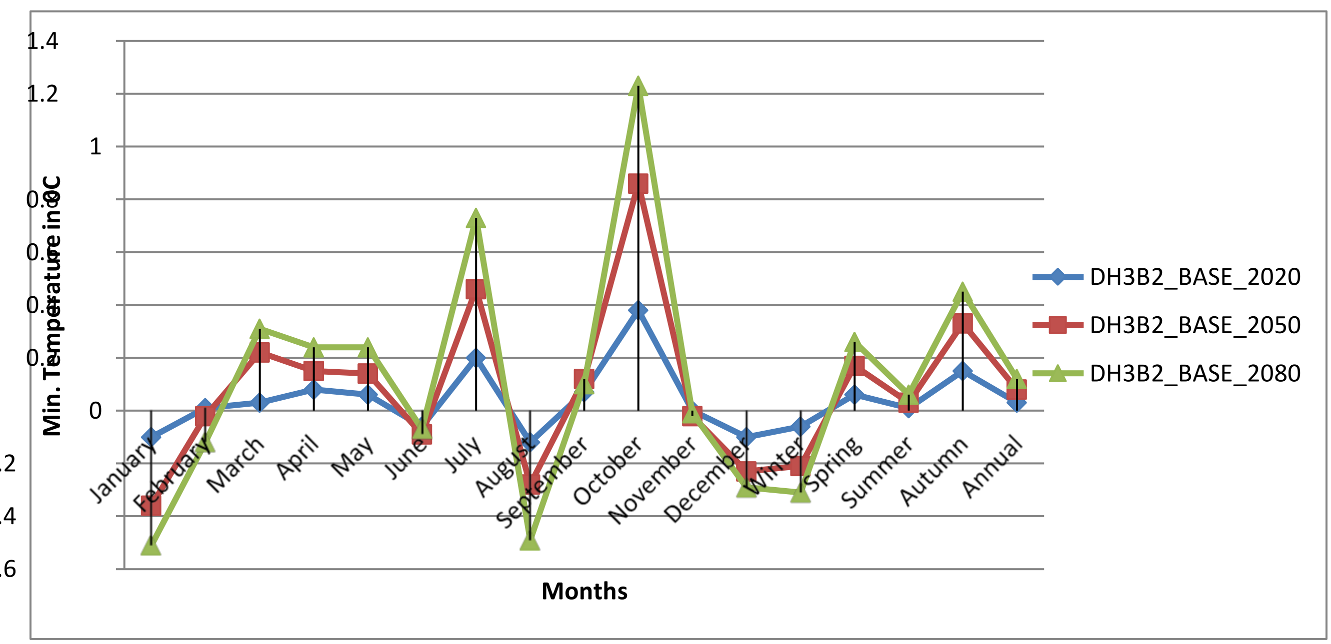

Figure 16 Change (Delta) of the future minimum temperature of the H3B2 scenario when compared with the base period.

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ISSN 2229-5518

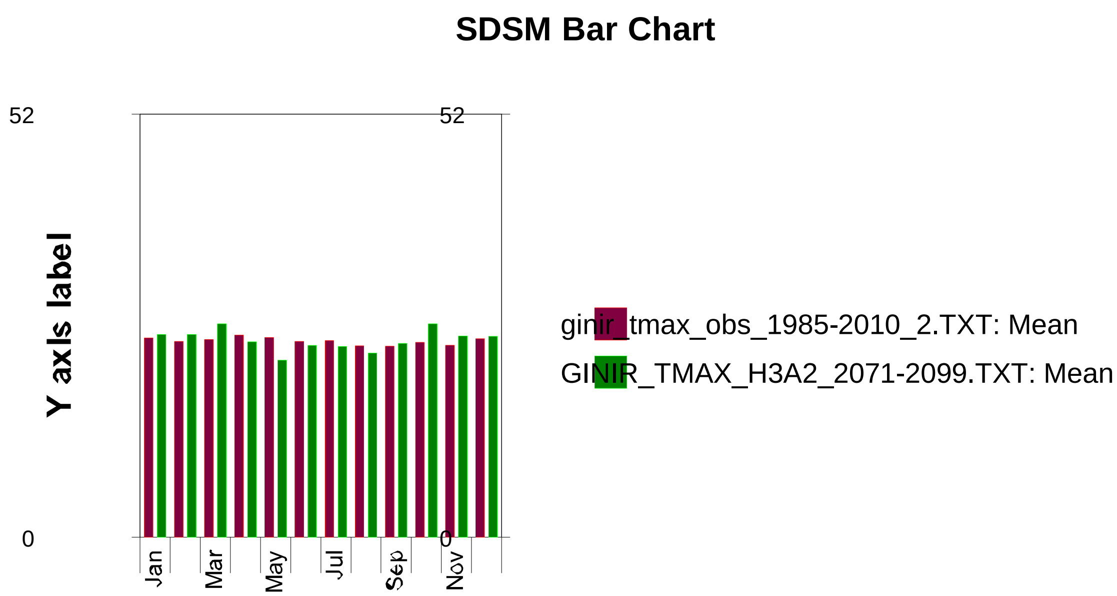

Figure 17 Base year Tmax of Ginir compared with the period 2080 for A2 scenario

As obtained from the modeled result, the fall maximum temperature of Ginir station was found to increase by 1.25°C with the A2a scenario and decrease by 0.08°C for the B2a scenario. Similarly, summer maximum temperature for Ginir station at 2080 was found to decrease by 0.71^{0}C with A2a scenario and also decrease by 0.15^{0}C with the B2a scenario. By increasing or decreasing the current mean maximum temperature of Ginir station for the fall and summer maximum temperature to be adjusted for the period 2080 and using the regression model of the net revenue over the climate and non-climate factors and assuming the retention of the value for the non-climate factors at their mean values, the net revenue per hectare at the year 2080 was found to increase by ETB 3,297.72 for the A2a scenario and again net revenue per hectare will increase by ETB414.81 per hectare by 2080 for B2a scenario. Thus, this study suggests that increase in the fall temperature and decrease in the summer temperature will result in a significant increase in net revenue per hectare at Ginir by 2080 for the A2a scenario. For the B2a scenario, still increase in net revenue is expected if not as such large when compared to A2a.

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5 CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study examined the extent of the economic impact of climate change on crop production as a result of marginal effects of temperature and rainfall, as well as to investigate the degree of observed climate change downscaled future projection. It also assessed the perception of the local community on climate change and adaptations mechanisms employed by farmers in response to climate change in Bale zone, Sinana, Ginir, Goro and Gololcha Districts. The estimated results indicated that climate change mainly temperature and precipitation are very influential for agricultural activities and climate impact also found to have linear and quadratic relationship with net revenue. The estimated results obtained from analysis of marginal effect indicated that there was significant effect of climate change on net revenue from crop production. Increasing temperature marginally during the fall season will increase the net revenue per hectare and increase in the square of summer temperature marginally reduces the net revenue per hectare.

From the climate only model, a 1^{O}C increase in spring temperature was found to increase the net revenue per hectare by ETB 1338.75. But a 1mm increase in the square of Fall Precipitation was found to decrease the net revenue per hectare by ETB 1.01. Moreover, for the regression model including other non-climate explanatory variables,it was found that altitude, use of improved seed, soil type, fall temperature and the square of summer temperature were found significant for the model fit with R^2 of 47%. With this model, for a 1m unit increase in altitude, net revenue per hectare will decrease by ETB 13.83, when a farmer chooses not to use improved seed; there was a decrease in net revenue by about ETB 1185.14. Similarly, when a farmer shifts from soil type of highly fertile to moderately fertile or from moderately fertile to infertile, there was a decrease of Net revenue per hectare by about ETB 2020.74 and a farmer who use additional 1 liter of weeding chemical per hectare was lost a net revenue per hectare of ETB 1660.12 more than a farmer who didn’t use additional weeding chemical. This suggests that proper care and consultation of experts is demanding to properly know advisable proportionate use of weeding chemicals per hectare. Similarly, 1^{0}C increase in mean fall temperature will increase the net revenue per hectare by ETB 840.03 and a 1^{0}C increase in the square of mean summer temperature will decrease the net revenue per hectare by ETB 67.42.Precipitation is found to be insignificant for this model.

To see the impact of climate change in the future time, future climate change scenarios produced for this study were based on the outputs of GCM results that are established on the SRES emission scenarios. As the objective of this study was to get indicative future climate ensembles, the scenarios developed were only for maximum temperature, minimum temperature, and precipitation values. The outputs of HadCM3 GCM model for the A2a and B2a emission scenarios were used to produce the future scenarios. The SDSM downscaling model was adopted to downscale the global scale outputs of the HadCM3 model outputs into the local level. Accordingly, both the A2a and B2a scenarios have shown increasing tendency of annual maximum temperature of 0.13^0C and 0.3^0C per annum respectively by 2080 for Ginir station. The base year model fit was found good for both A2a and B2a scenarios. As obtained from the modeled result, the fall maximum temperature of Ginir station was found to increase by $1,25^o$C with the A2a scenario and decrease by 0.08^oC for the B2a scenario. Similarly, summer maximum temperature for Ginir station at 2080 was found to decrease by 0.71^0C with A2a scenario and also decrease by 0.15^0C with the B2a scenario.

By increasing or decreasing the current mean maximum temperature of Ginir station for the fall and summer maximum temperature to be adjusted for the period 2080 and using the regression model of the net revenue over the climate and non-climate factors and assuming the retention of the value for the non-climate factors at their mean values, the net revenue per hectare by the year 2080 was found to increase by ETB 3,297.72 for the A2a scenario and again net revenue per hectare will increase by ETB414.81 per hectare by 2080 for B2a scenario. Thus, this study suggested that increase in the fall temperature and decrease in the summer temperature will result in a significant increase in net revenue per hectare at Ginir by 2080 for the A2a scenario. For the B2a scenario, still increase in net revenue is expected if not as such large when compared to the A2a scenario. Since precipitation was not significant in the regression model, the impact of precipitation on net revenue was not discussed.

5.2. Recommendation

As seen from the result, climate was found to play vital role to optimize net revenue per hectare. As per the result of this study, increase in fall temperature and decrease in summer temperature will increase net revenue per hectare. However, increase in summer temperature will decrease the net revenue per hectare as seen from the climate only model. But as seen from the future trend, summer temperature is increasing with increasing net revenue per hectare. There will be a potential tendency for the net revenue per hectare to decrease in the scenario as well as the A2a for all the three time periods 2020, 2050 and 2080. Thus, the following points are recommended for climate change adaptation and mitigation.

- It needs to support farmers' adaptation capacity through improving their crop production verities to overcome future scenarios of climate change impacts.
  - Proper and efficient extension services are also needed for feasible adaptation mechanism
- There should be promotion activities to enhance farmers' participation on creating climate resilient community.
  - Local community adaptation mechanisms which are environmentally sound and effective need to be promoted.
- Government policies should strengthen the existing adaptation strategies practiced by farmers and support adaptation technologies that have the potential to reduce climate change due to natural and human induce factors.
- Further and continuous research is needed to understand the impacts of climate change on agricultural crops.

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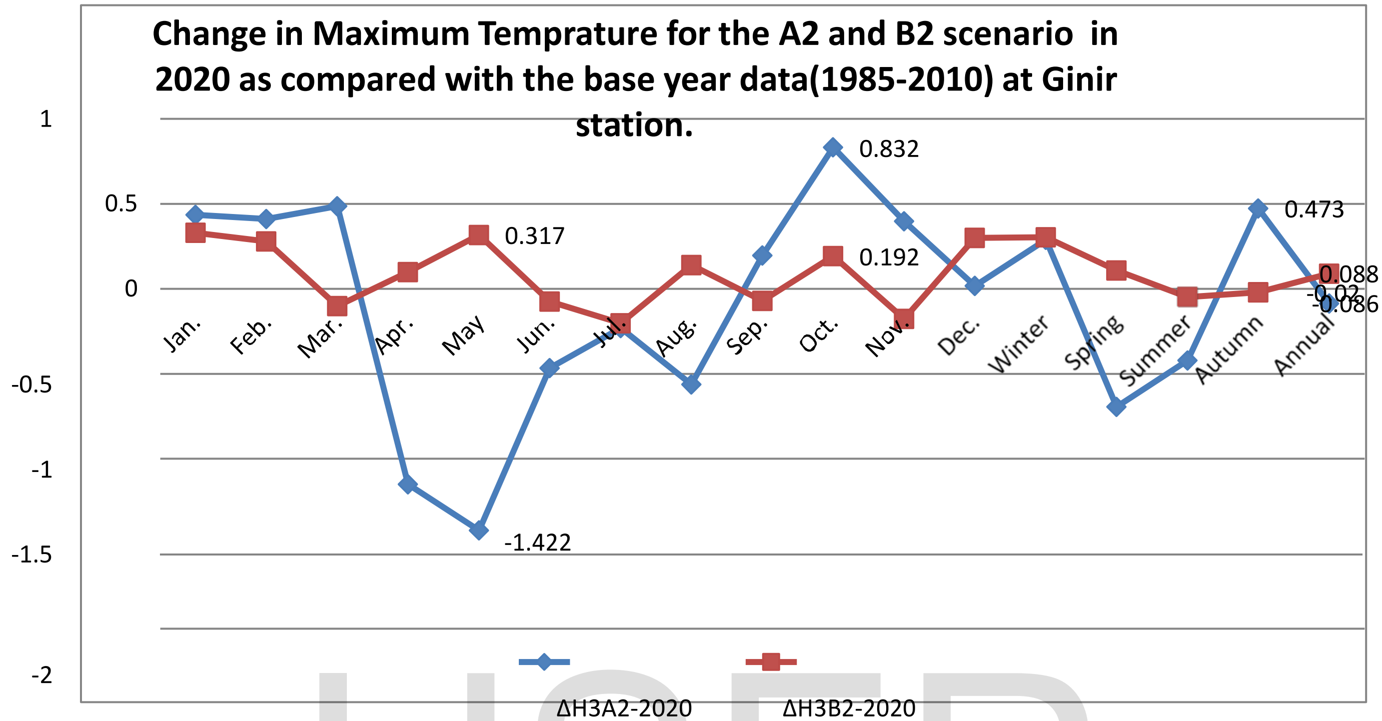
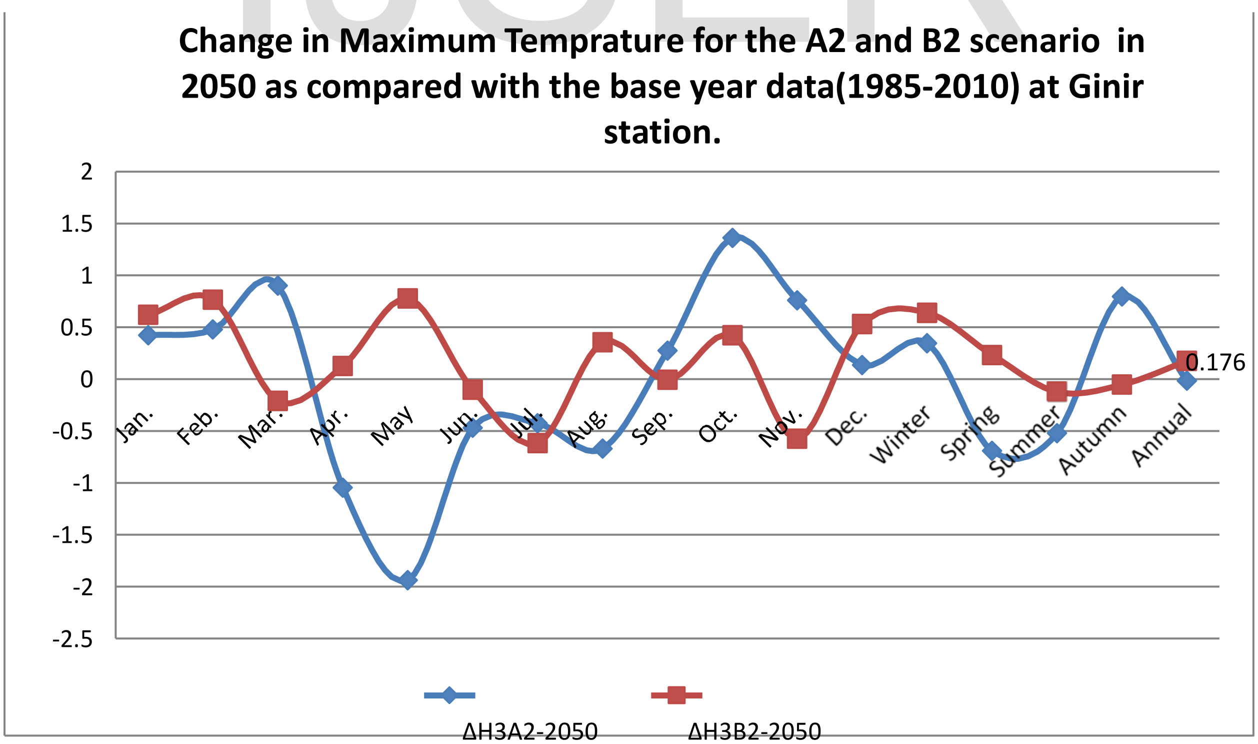
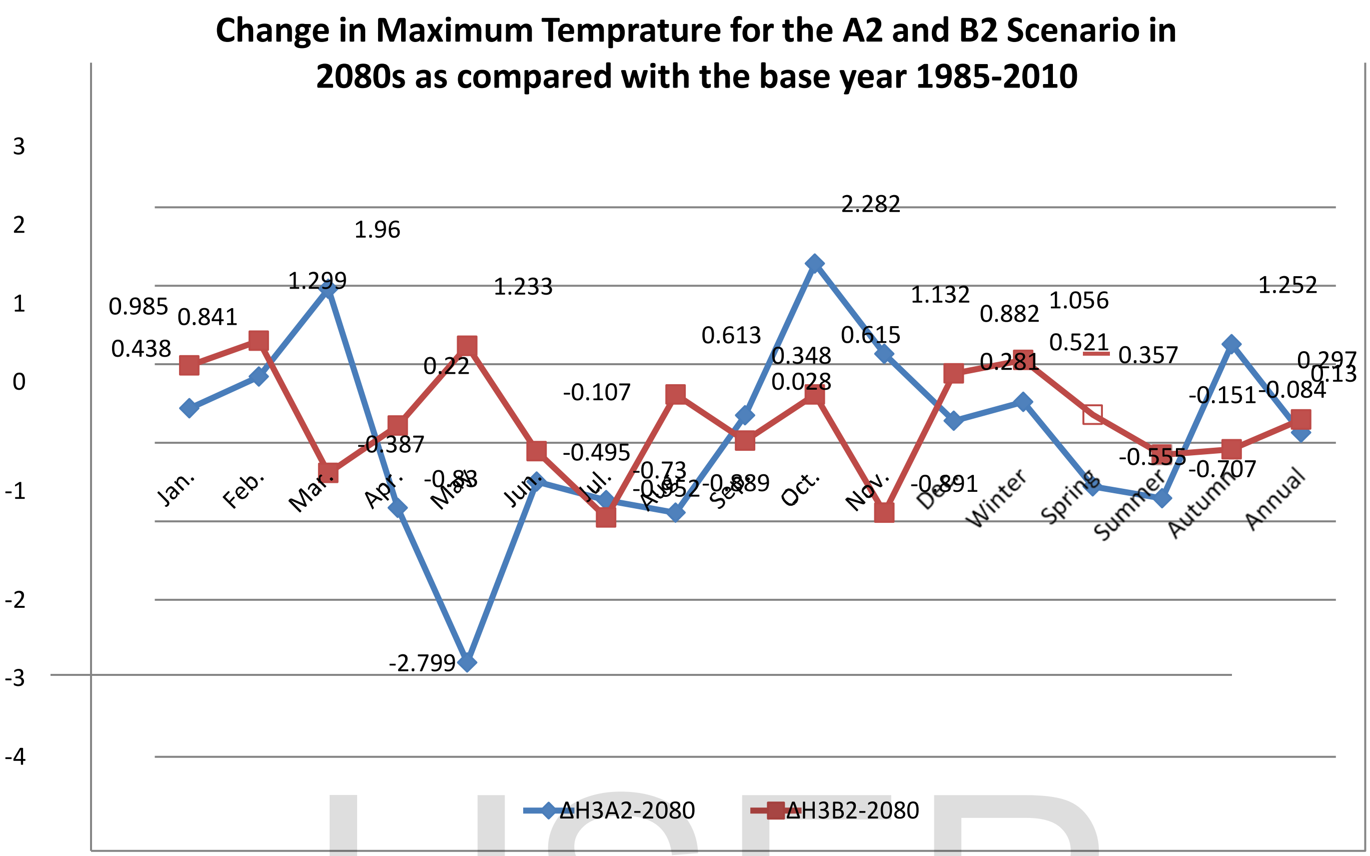
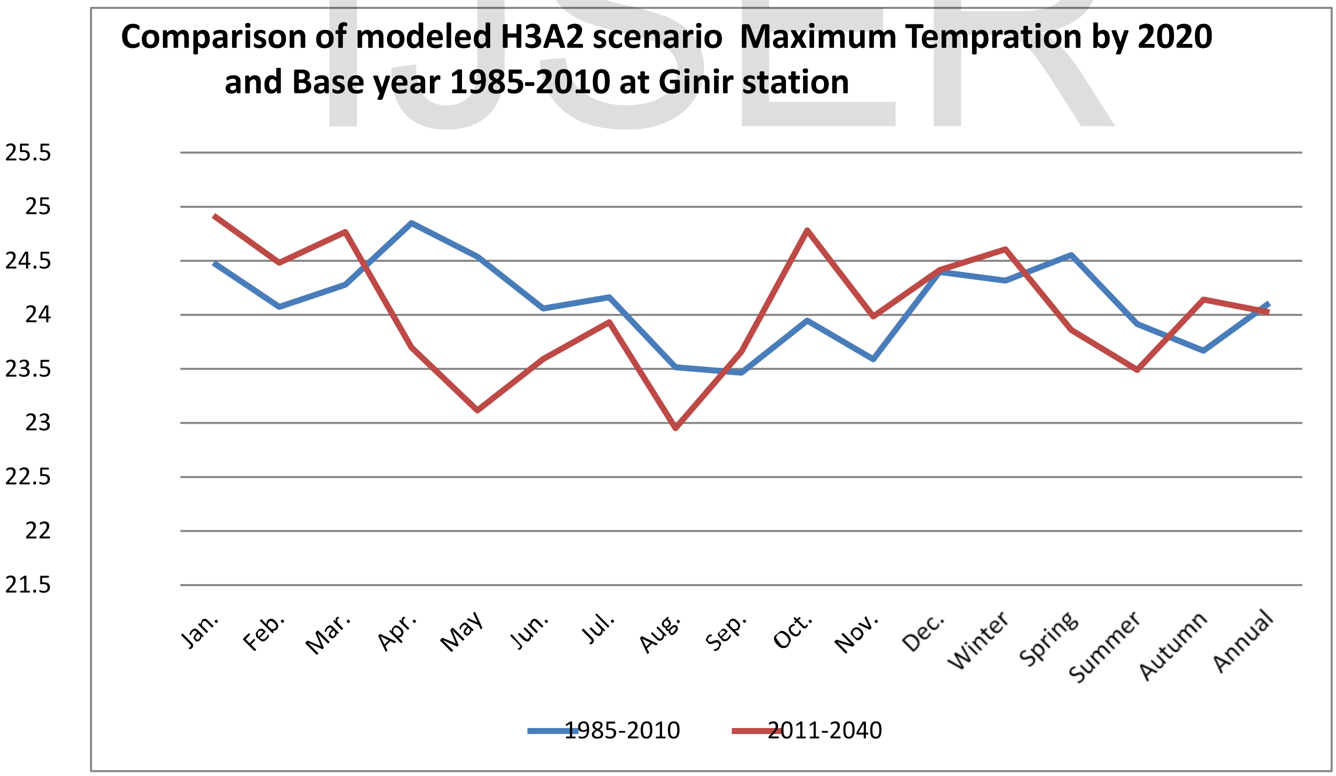
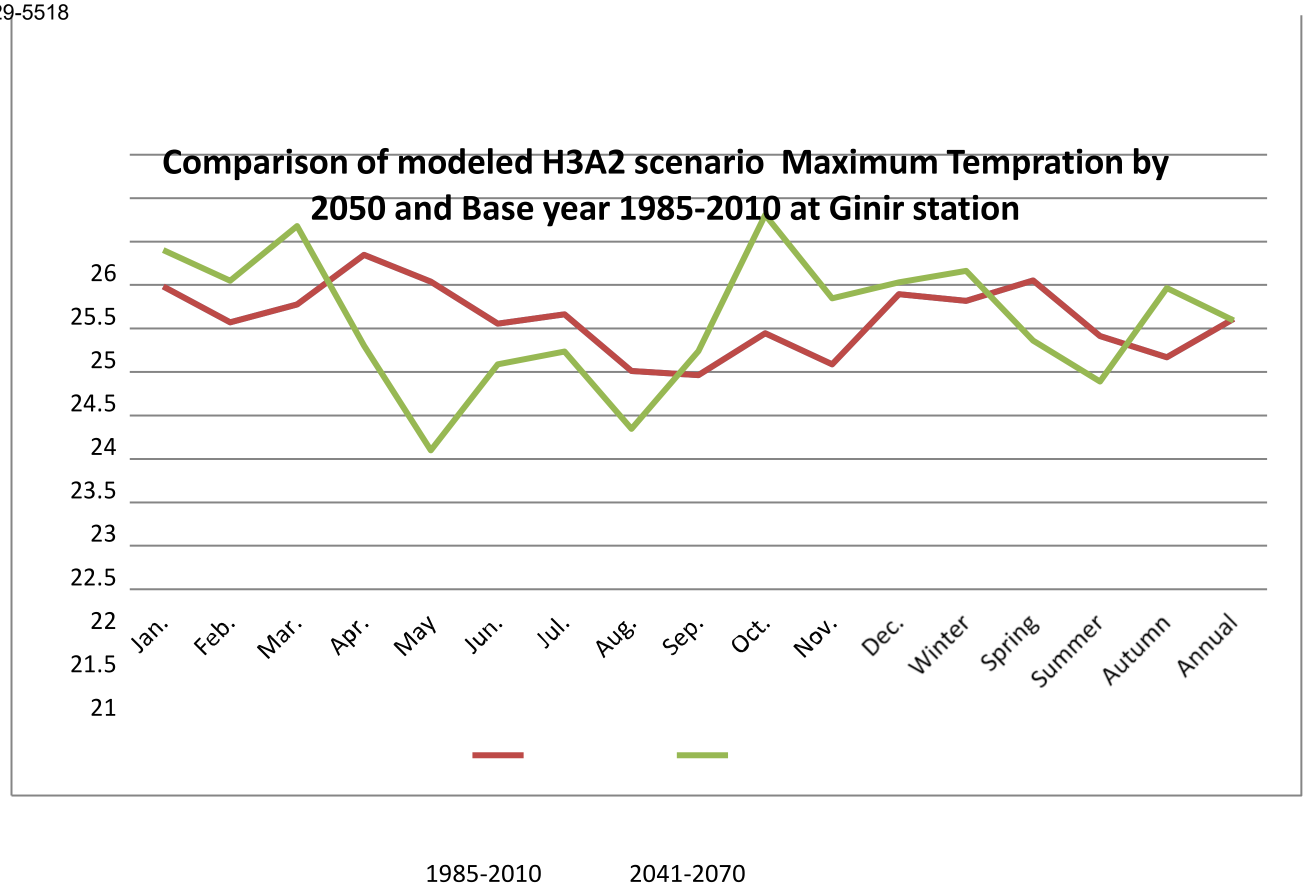
Annex I

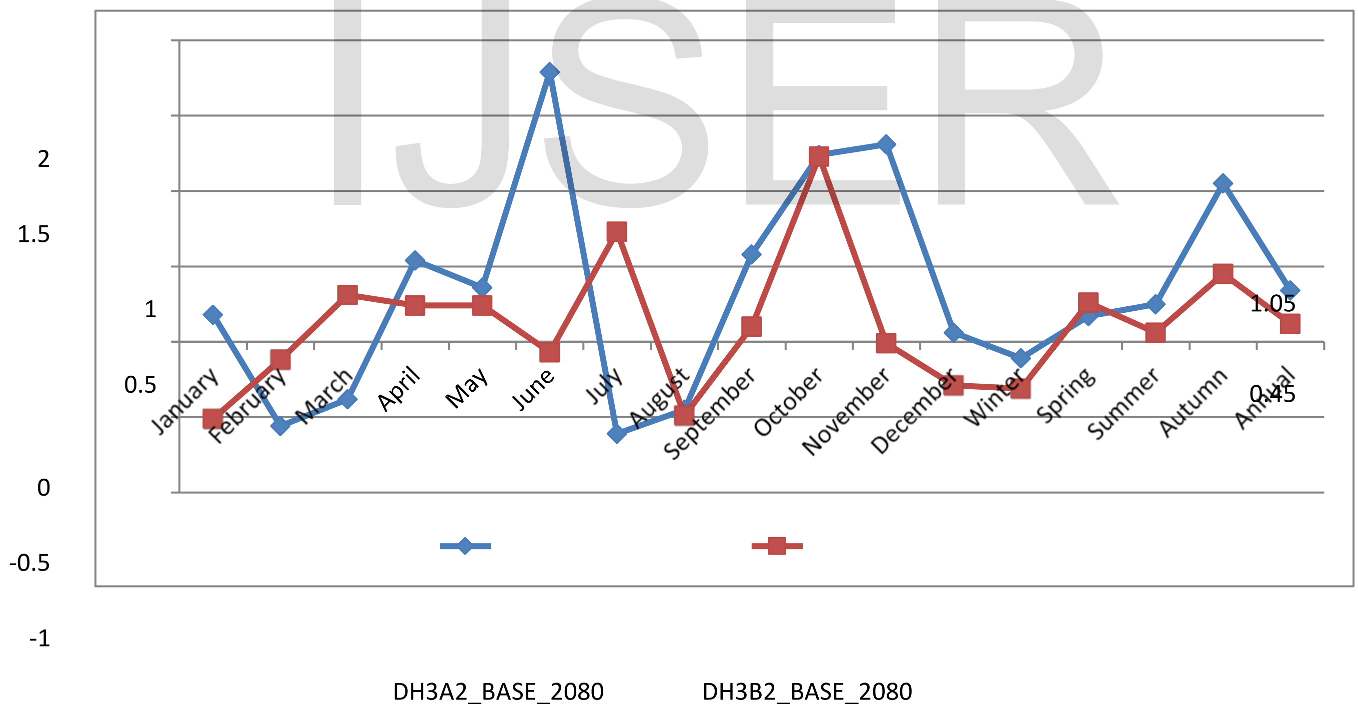

Change in Maximum Temprature for the A2 and B2 scenario in 2020 as compared with the base year data(1985-2010) at Ginir station.
1
0.5
0
-0.5
-1
-1.5
-2
0.832
0.317
0.192
0.473
0.088
-0.02
-0.086
-1.422
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Winter
Spring
Summer
Autumn
Annual
ΔH3A2-2020
ΔH3B2-2020

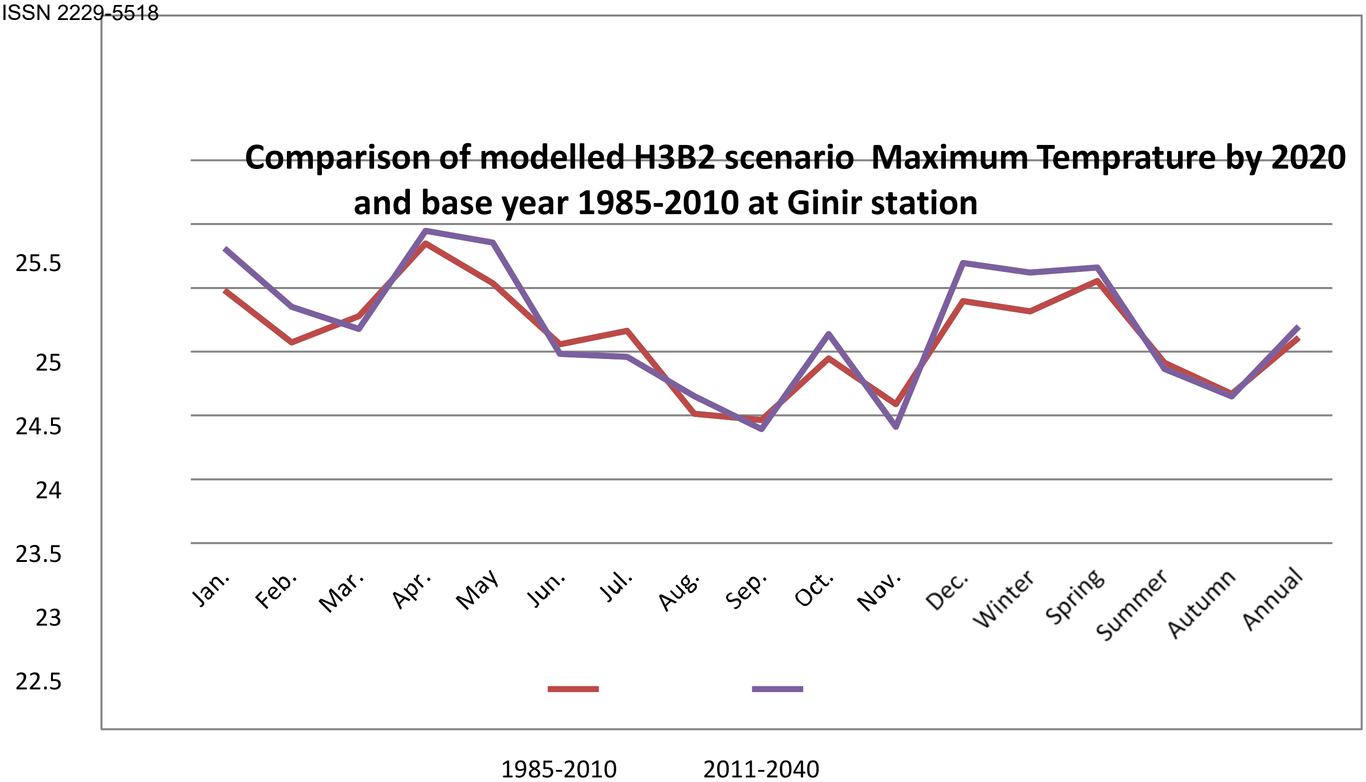

Change in Maximum Temprature for the A2 and B2 scenario in 2050 as compared with the base year data(1985-2010) at Ginir station.
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0.176
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Winter
Spring
Summer
Autumn
Annual
ΔH3A2-2050
ΔH3B2-2050

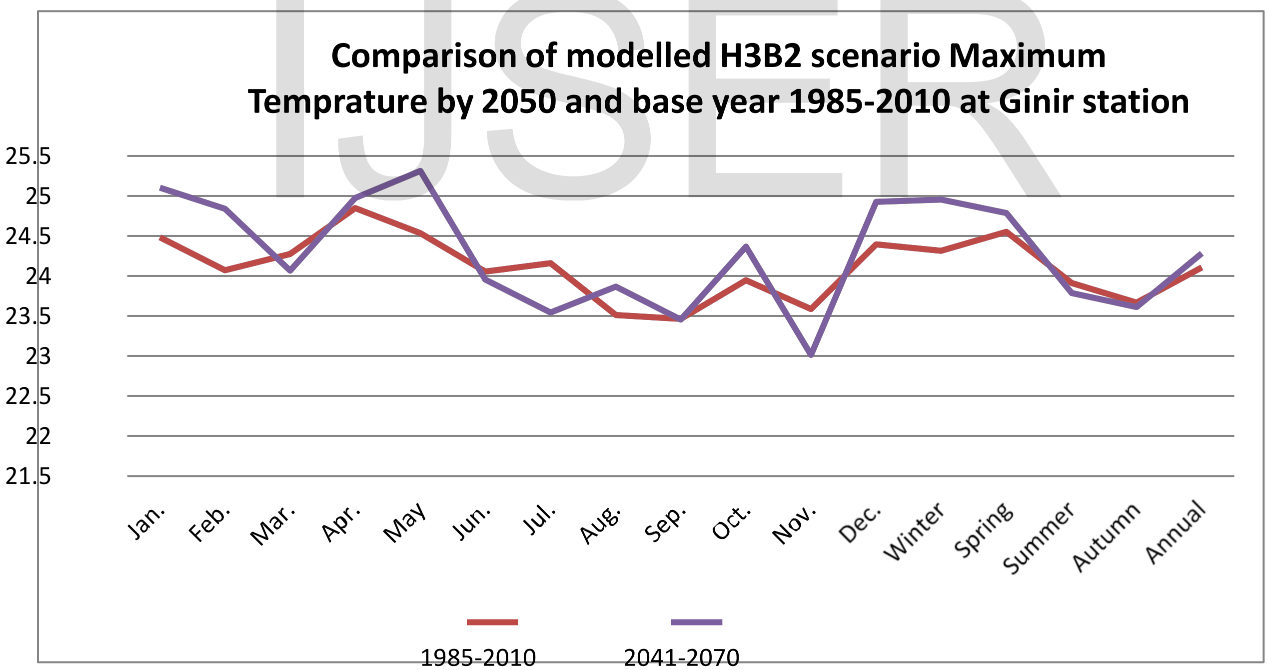

Change in Maximum Temprature for the A2 and B2 Scenario in 2080s as compared with the base year 1985-2010
3
2
1
0
-1
-2
-3
-4
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Winter
Spring
Summer
Autumn
Annual
0.985
0.841
0.438
1.299
1.96
0.22
-0.387
-0.83
-2.799
1.233
-0.107
-0.495
-0.73
-0.952
-0.889
0.613
0.348
0.028
2.282
0.615
1.132
-0.891
0.882
0.281
1.056
0.521
0.357
-0.555
-0.707
-0.151
1.252
-0.084
0.297
0.13
ΔH3A2-2080
ΔH3B2-2080

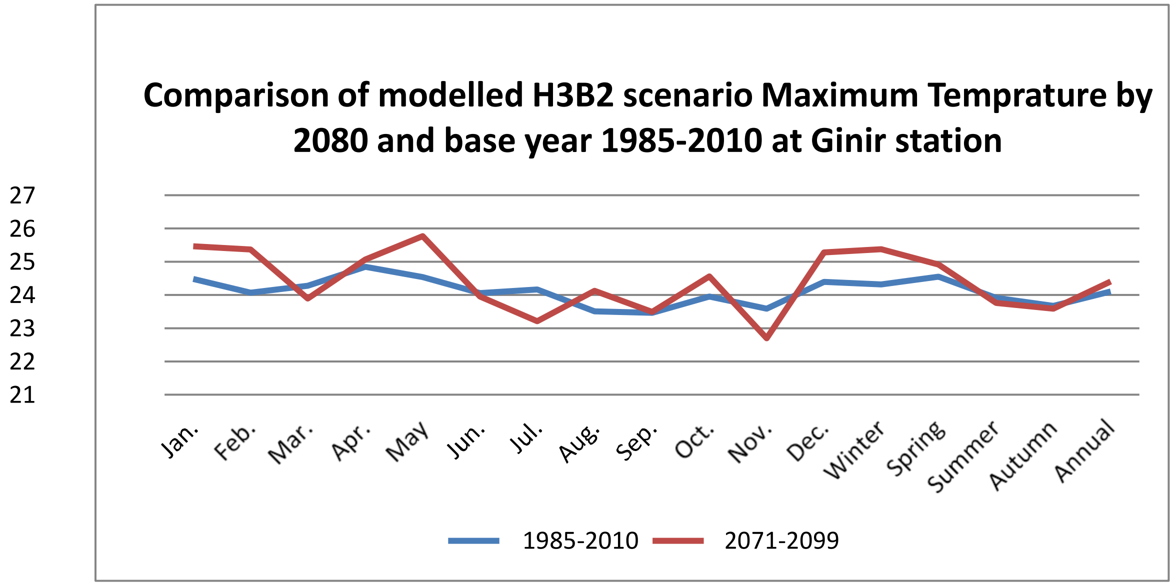

Comparison of modeled H3A2 scenario Maximum Tempration by 2020 and Base year 1985-2010 at Ginir station
25.5
25
24.5
24
23.5
23
22.5
22
21.5
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Winter
Spring
Summer
Autumn
Annual
1985-2010
2011-2040

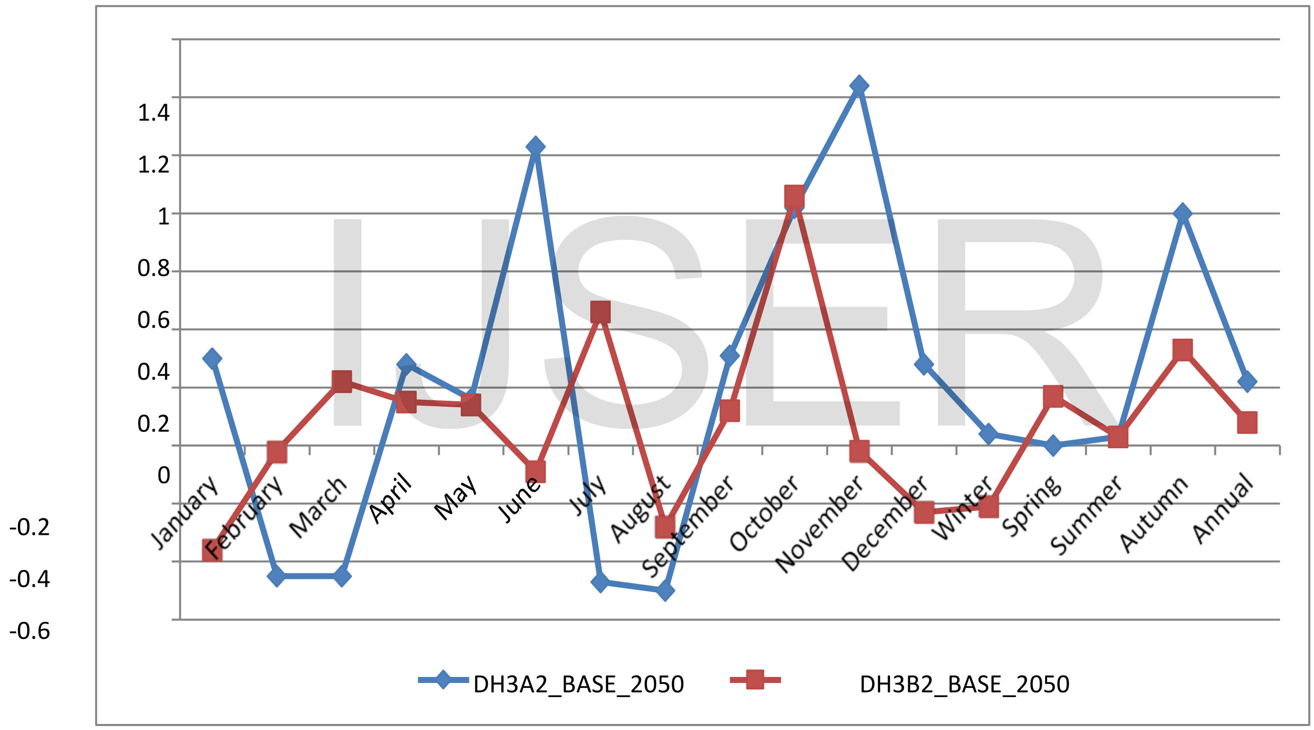

Comparison of modeled H3A2 scenario Maximum Tempration by 2050 and Base year 1985-2010 at Ginir station
26
25.5
25
24.5
24
23.5
23
22.5
22
21.5
21
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Winter
Spring
Summer
Autumn
Annual
1985-2010
2041-2070

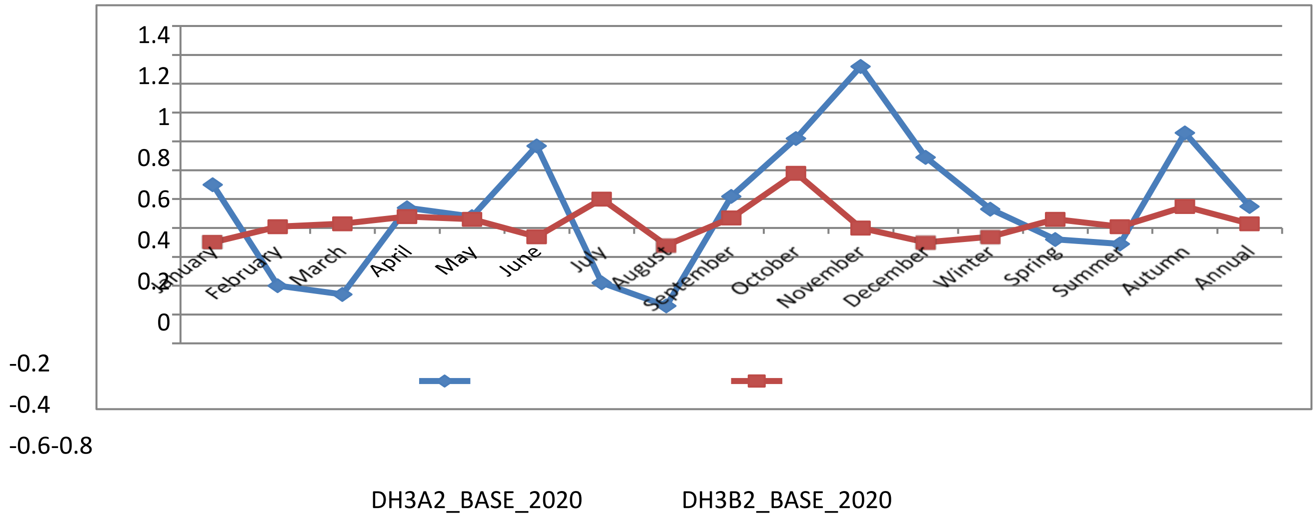

2
1.5
1
0.5
0
-0.5
-1
January
February
March
April
May
June
July
August
September
October
November
December
Winter
Spring
Summer
Autumn
Annual
1.05
0.45
DH3A2_BASE_2080
DH3B2_BASE_2080

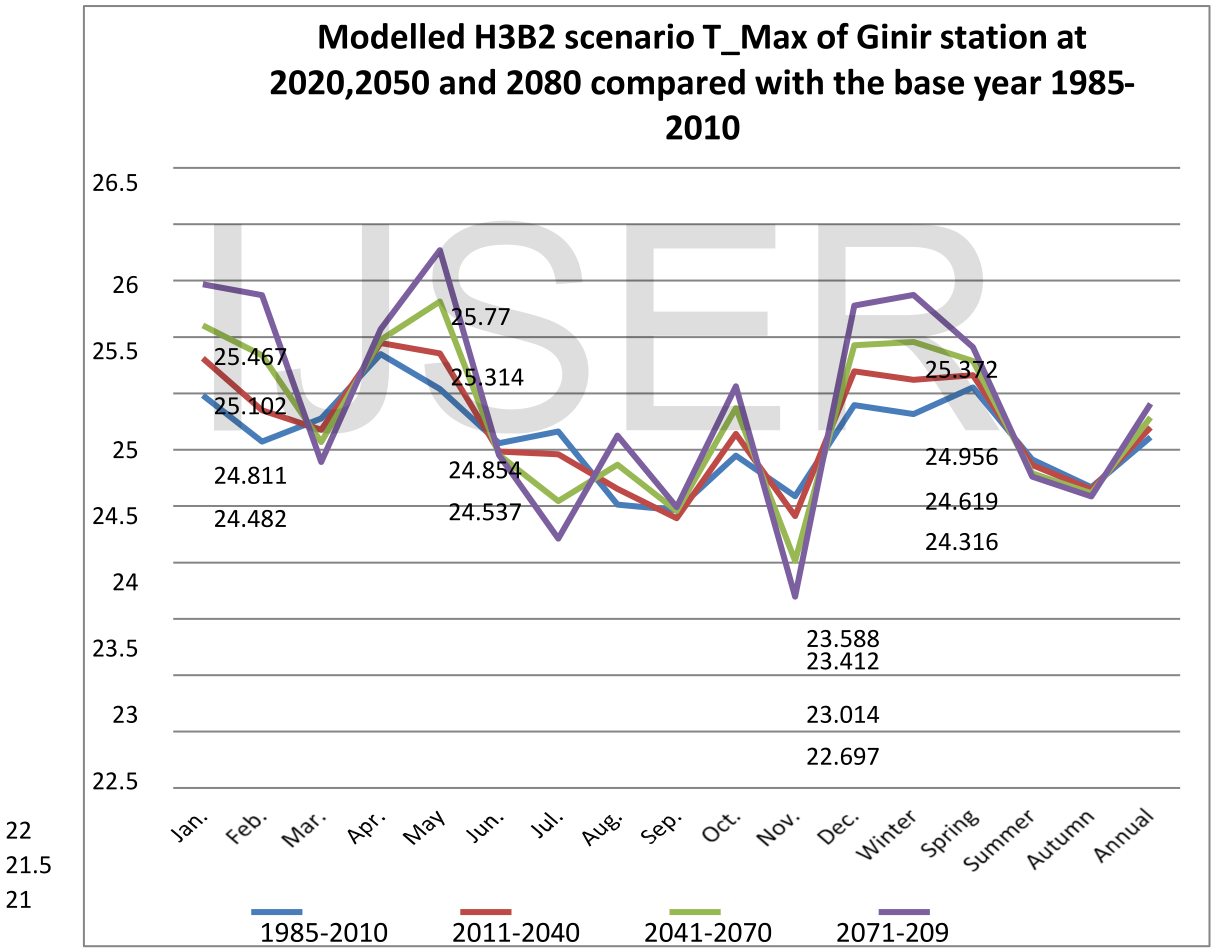

Comparison of modelled H3B2 scenario Maximum Temprature by 2020 and base year 1985-2010 at Ginir station
25.5
25
24.5
24
23.5
23
22.5
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Winter
Spring
Summer
Autumn
Annual
1985-2010
2011-2040


Comparison of modelled H3B2 scenario Maximum Temprature by 2050 and base year 1985-2010 at Ginir station
25.5
25
24.5
24
23.5
23
22.5
22
21.5
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Winter
Spring
Summer
Autumn
Annual
1985-2010
2041-2070


Comparison of modelled H3B2 scenario Maximum Temprature by 2080 and base year 1985-2010 at Ginir station
27
26
25
24
23
22
21
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Winter
Spring
Summer
Autumn
Annual
1985-2010
2071-2099


1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
January
February
March
April
May
June
July
August
September
October
November
December
Winter
Spring
Summer
Autumn
Annual
DH3A2_BASE_2050
DH3B2_BASE_2050


1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6-0.8
January
February
March
April
May
June
July
August
September
October
November
December
Winter
Spring
Summer
Autumn
Annual
DH3A2_BASE_2020
DH3B2_BASE_2020


Modelled H3B2 scenario T_Max of Ginir station at 2020,2050 and 2080 compared with the base year 1985-2010
26.5
26
25.5
25
24.5
24
23.5
23
22.5
22
21.5
21
25.467
25.102
24.811
24.482
25.77
25.314
24.854
24.537
23.588
23.412
23.014
22.697
25.372
24.956
24.619
24.316
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Winter
Spring
Summer
Autumn
Annual
1985-2010
2011-2040
2041-2070
2071-209