# Impact of Climate Change on Irrigation Case Study on: Wonji Shoa Sugar Plantation Estate

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# Abstract

Irrigation is significant in increasing agriculture production and productivity for sustainability of country's economy. Impacts on existing activities for irrigation design and management system is obvious due to rapid change of climate system. This paper future focus to evaluate the influence of changing climate on the crop yield and irrigation requirement for Wonji Shoa Sugarcane Plantation Estate. For future climate data, it used the results of projections of cordex regional climate model (RCM) with bias correction for medium concentration representative path way 4.5RCP and high concentration representative path way 8.5RCP scenario. The down-scaled data were then used as input to the AQUACROP model. The time series indicate a significant increasing trend in maximum and minimum temperature values and a slight increasing trend in precipitation for both 4.5rcp and 8.5 rcp scenarios. The evapotranspiration shows an increases in 20.34%, 20.12%, 23.59% and 24.36% for 8.5 rcp in the period of 2020s, 2040s, 2060s, 2080s respectively. For 4.5rcp scenario the change is in about 8.4%, 11.65%, 13.22%, and 15.85% for the period of 2020s, 2040s, 2060s, and 2080s respectively. The model output shows that there is an annual increase in yield. For 8.5 rcp scenarios, the incensement is 6.2%, 7.84, 11.03% and 14.48% in 2020s, 2040s, 2060s and 2080s respectively. For 4.5 rcp scenarios the increment is much lower compared to 8.5rcp scenarios. But there is steel increasing in yield for 4.5rcp. The change is 0.3%, 1.8%, 7.02%, and 4.82% for the period of 2020s, 2040s, 2060s, and 2080s respectively.


# 1. Introduction

The global mean surface temperature changes for the period 2016–2035 relative to 1986–2005 will likely be in the range 0.3°C to 0.7°C [1]. In Ethiopia, observations show a year-to-year variation for rainfall events in all over the country [2]. While regional models predict increase in rainfall, higher resolution analyses for Ethiopia suggest with spatial differences, there are both increases and decreases in the overall rainfall averages. The challenges faced by the agricultural sector under the climate change scenarios are to deliver food security for an increasing world population while protecting the environment and the functioning of its ecosystems. Climate change has become significant threat to agriculture and food security across the globe. Projected changes in temperature, precipitation and $CO_2$ concentration are expected to significantly impact crop productivity [3]. Erratic temperature and precipitation conditions are shown to often occur concurrently, with dry growing seasons more likely to be hotter, have larger drought indices, and have larger vapor pressure deficits. This leads to the confluence of a variety of climate conditions that negatively impact crop yields [4].

The Intergovernmental Panel on Climate Change's [5] findings suggests that developing countries like Ethiopia will be more vulnerable to climate change due to their economic, climatic and geographic settings. Climate change can affect multiple features of aquatic resources (e.g., quantity and quality, high and low flow extremes, timing of events, water temperature, etc). All these aspects affect livelihoods in the basin but have not received attention in planning for future water allocation and design of water infrastructures yet [6].

Sugarcane (*Saccharum* spp. hybrids) is tropical grass broadly grown in both hemispheres in over 120 countries worldwide. It is an important agro industrial cash crop, providing raw material for different sugar industries and plays crucial role in the economy of several countries [7]. Ethiopia is among the country's which are struggling to cover their high demands for sugar all over the country and the world though we can't cover even the country need. Having the above mentioned and other related problems, it is imperative to understand effect of upcoming climate variation on hydrometeorology, subsequent influence on the lives of people and sugar products. This paper simulated the impacts of climate change on sugarcane in wonji shoa plantation using the Aquacrop model and a range of two projected downscaled climate scenarios, to estimate the likely future impacts on the crop in terms of yield and irrigation water requirement

## 2. Methodology

# 2.1 Description of the study area

The study area, Wonji–Shoa Sugar Estate lies downstream of the Koka Dam in the Central Rift Valley of Ethiopia in the Awash River Basin, 110 km southeast of Addis Ababa and 10 km south of Adama by road approximately between 8°21' to 8°29' N 39°12' to 39°18' E (Fig. 2, [8]. The estate (including out growers) has a total area of about 8000 ha (excluding the current under expansion) and the factory has a total crushing capacity of 3500 TCD (ton of cane). Approximately 9319 households (6184 male-headed and 3135 female-headed) participate in the out-grower scheme. Each household possesses between 0.2 and 6 ha of land [9] and the out-growers supply 60% of the total sugarcane crushed per year.

The Wonji-Shoa Irrigation Scheme is found at an altitude of approximately 1,500 meters above sea level (m.a.s.l.). In the estate, generally, the slope of the farm is very gentle and regular.

has a semi-arid climate and obtains an average annual rainfall of 831.2 mm, highest daily evapotranspiration of 4.5 mm, mean annual maximum and minimum temperatures of 27.6°C and 15.2°C, respectively. The soil of WSSE are mainly Andosols, Fluvisols, Leptosols, and Phaeozemes, according to the FAO soil classification.

The main forms of land cover use in the Wonjishoa irrigated land is perennial crop cover dominated by sugar cane plantation and uses high amount of water from Awash River during dry season of the year.

# 2.2 Data collocation

# 3.2.1 Sources and types of data

To meet the objectives of this research, different types of data were collected from both primary and secondary data sources including satellite imagery and field data. Data collected included spatial data, hydrological data, and meteorological data.

#### Meteorological Data

Meteorological data was required since it will used as input to the Aqua crop model in base line scenario. The future metrological records which are already downscaled are available in different climate portal and used with bias correction. Based on these objectives, the meteorological data required for this study were collected from the Wonji Shoa sugarcane estate research center weather station, Ethiopian National Meteorological Services Agency (NMSA) at Addis Ababa. The daily meteorological data collected were precipitation, maximum and minimum temperature, relative humidity, wind speed and sunshine hours.

#### Crop, Irrigation and Soil Data

The crop, irrigation and soil data are used in Aqua crop model for simulation of the system (wonjishoa plantation state). The soils of WSSE are of alluvial-coluvial origin established under hot, tropical environments. Texturally, the soil can be categorized into light (course textured) and heavy (clayey black) soils. The estate sidetracked irrigation water from Awash River using centrifugal pumps and then to masonry lined main canal. Field water application is through block-ended furrow irrigation system and the excess water from the plantation fields are worn out through the network of surface drains. The main crops cultivated are sugarcane, haricot bean and crotalaria. Sugarcane is planted at a rate of 16–18 t/ha in the estate and it is cultivated as perennial mono crop [2].

#### Future Climate Scenario Data

The climate scenario data used here are freely available data which is already down scaled and can be used directly by bias correcting for model output of Cordex of four scenarios rcp2.5,rcp4.5, rcp6.5 and rcp8.5 produced by greenhouse gas, sulphate aerosol, and solar forcing and NCEP reanalysis data. The considered climate data are for medium and high (4.5rcp and8.5 rcp) scenarios of precipitation, maximum temperature and minimum temperature.

## 2.3 Method of analysis and procedures

Investigation of climate change impact in irrigation consists of the following steps:

1. Using Coordinated Regional climate Downscaling Experiment over African domain (CORDEX-Africa) with Coupled Model Inter-comparison Project Phase 5 (CMIP5 ) simulations under Representative Concentration Pathway s (under the effect of increasing greenhouse gases) for wonji shoa plantation estate compatible with Aquacrop model and,
2. Use of Aquacrop model to simulate the effects of climate change on small scale irrigation.

## 2.3.1 Coordinated Regional Downscaling Experiment (CORDEX)

Coupled Atmosphere–Ocean General Circulation Models (GCMs) used for studding current and future climate globally, which simulate the climate of the Earth at spatial determination of a few hundred kilometers. To detained the local impacts of topography and land surface features on climate and provide a better explanation of extreme events, limited-area regional climate models (RCMs) are used to downscale GCM amount produced [10]. The Coordinated Regional Climate Downscaling Experiment (CORDEX) [10] is an initiative funded by the World Climate Research Program. The goal is to scheme a set of standardized research intended at scale back GCM predictions from the Coupled Model Inter comparison Project phase 5 (CMIP5) [5] in the widely held of the land areas of the world, both via RCMs and statistical techniques (dynamical and statistical downscaling, respectively).\

**Bias Correction of the row Rcm Data**

Climate models often provide biased representations of observed time series and, making correction procedures necessary [11]. Bias correction actions employ a transformation algorithm for correcting RCM output. The method used for bias correction of the study is the linear-scaling approach works with monthly correction values based on the changes between observed and present-day simulated values. By definition, corrected RCM simulations will faultlessly agree in their monthly mean values with the observations. Precipitation is corrected with a factor based on the ratio of long-term monthly mean observed and control run data;

$$p^*_{cuntr}(d) = P_{cuntr}(d) . \{\mu_m(p_{obs}(d))/\mu_m(p_{cuntr}(d))\}$$

$$p^*_{scen}(d) = p_{scen}(d) . \{\mu_m(p_{obs}(d))/\mu_m(p_{cuntr}(d))\}$$

$$T^*_{cuntr}(d) = T_{cuntr}(d) + \mu_m . (T_{obs}(d)) - \mu_m(T_{cuntr}(d))$$

$$T^*_{scen}(d) = T_{scen}(d) + \mu_m . (T_{obs}(d)) - \mu_m(T_{cuntr}(d))$$

Where;

* -Final bias-corrected

Cuntr - RCM simulated 1961–1990

μ - Monthly mean (location parameter of Gaussian distribution)

Scen - RCM-simulated 2005–2099

# 2.3.2 Aquacrop Model simulation

AquaCrop is the FAO crop-model to simulate harvest reaction to water. It is intended to balance ease, accuracy and robustness, and is predominantly suited to address conditions where water is a key controlling element in crop production. The system (the interaction between plant and soil) also affected by management which (field and irrigation) which is fertility, when and in what amount to apply irrigation water. The system link with the outside world which is upper boundary. At upper boundary there is weather condition which describe what is the rain fall, how many energies' available to vaporize water and what is the concentration of carbon dioxide. At lower boundary ground water table is linked to the system in which water commencing the system drain and the water table near to the soil and subsoil then water move by capillary rise from the water table to the sub soil.

# 2.3.2.1 Conditions in upper boundary

The upper boundary is about the weather condition and it consists reference evapotranspiration, rainfall, minimum and maximum temperature and annual $co_2$ concentration. From metrological data recorded in wonji shoa station is used to compute reference evapotranspiration.it express the evaporating power of the atmosphere.it determine the rate of transpiration and evaporation.in Aquacrop it can be calculated from metrological data. Next to Eto Aquacrop require minimum and maximum temperature.it required to calculate growing degree days which determine the speed of crop development. They are also cold and heat stress in Aquacrop which affect yield and biomass production. Eto, minimum and maximum temperature can be entering daily,10 daily or monthly. However, Aquacrop will need, work and simulate in daily time steps. In Wonjishoa case both base line and future data (Eto, minimum and maximum temperature and rainfall) are in daily steps. Aquacrop also require rainfall data to update daily water balance and to simulate water stress. Finally Aquacrop need mean annual $co_2$ concentration because it affects biomass making and crop transpiration. It consists recorded and projected(future) concentrations. The later one is used for climate alteration scenarios.

#### 2.3.3 Determination of net irrigation requirement $(I_{net})$

The resolution of net irrigation makes use of threshold. It's the allowable root zone depletion. When in the lack of rainfall, the irrigation volume drops below the allowable root zone then small amount of water will be injected in the root zone to keep the soil water content at that level for such day. Toward the end of the season, the sum of the added water is the net irrigation.

$$I_{net} = \sum \text{wateradded}$$

These are net requirement because does not consider extra water that has to be practical to the field to account for conveyance losses or the uneven distribution of irrigation water on the field. To run Aquacrop in the net irrigation mode, we need to specify the allowable root zone depletion which is expressed in fraction of RAW (rarely available water). RAW is zero when the soil water content is in field capacity and 100% at the threshold for stomatal closure. So the allowable root zone depletion is expressed in percentage of RAW.

## 3. Results And Discussion

# 3.1 Climate Projection

The projected climate result during base line and future period is described here. The result of downscaled RCM of more than 15 models for the rcp4.5 (Medium representative concentration pathway) and rcp8.5 (high-representative concentration pathway) Scenarios from 1990 to 2099 compared with the base line (1990–2016) period data get from wonjishoa sugar cane estate research center.

# 3.1.1 Base line Scenario

**Maximum Temperature, Minimum temperature and Precipitation**

The monthly mean maximum, minimum temperature and Precipitation obtained from RCM model (CORDEX) and with bias correcting gives the following results for the baseline period (1990–2016) of both in rcp4.5 and rcp8.5 emission scenarios as shown in Fig. 3.

The monthly maximum and minimum temperature for 4.5 and 8.5 RCP scenarios in the baseline period shows a reasonably good agreement with the observed temperature for all months. Bias corrected RCM model result performs reasonably well in estimating the mean monthly precipitation satisfactory given the fact that precipitation downscaling is necessarily more problematic than temperature.

# 3.2 Downscaled RCM for Future Scenario

The climate scenario result for future period was developed from downscaled GCM for two representative concentration pathway (4.5and 8.5 rcp) for 90 years and the analysis was done based on four 20-year periods centered on the2020s (2020–2039), 2040s (2040–2059), 2060s (2060–2079) and 2080s (2080–2099). All the comparisons in the following analysis were done with respect to the baseline period (1990–2016) data at wonji shoa research center.

**Maximum Temperature, Minimum temperature and Precipitation**

The downscaled minimum temperature shows an increasing trend for all months in all future time horizons for both 4.5 rcp and 8.5 scenarios. The average annual minimum temperature in 2020s will be increased by 1.35$^{\circ}C$ and 1.59°C for 4.5rcp and 8.5rcp scenario respectively. For the 2040s periods the average annual minimum temperature will be increased by 1.79°C and 2.7°C for 4.5rcp and 8.5rcp scenario respectively. For the 2060s periods the average annual minimum temperature will be increased by 2.59°C and 3.63°C for 4.5rcp and 8.5rcp scenario respectively. For the late 21 century the average annual minimum temperature will be increased by 2.79°C and 4.09°C for 4.5rcp and 8.5rcp scenario respectively

For WonjiShoa the overall analysis (2011–2099) of maximum temperature showed that there may be increasing trends in both scenarios (4.5rcp and 8.5rcp). The average annual maximum temperature in 2020s will be increased by 1.21°C and 1.16°C for 4.5rcp and 8.5rcp scenario respectively. For the 2040s periods the average annual maximum temperature will be increased by 1.48°C and 1.93°C for 4.5rcp and 8.5rcp scenario respectively. For the 2060s periods the average annual maximum temperature will be increased by 1.52°Cand 2.98°C for 4.5rcp and 8.5rcp scenario respectively. For the 2068s periods the average annual maximum temperature will be increased by 1.97°Cand 4.17°C for 4.5rcp and 8.5rcp scenario respectively. Increasing maximum temperature showed more variation at the monthly time step with arrange from 0.8°C to 1.45°C in 2020s, 1.01°C to 2.6°C in 2040s, 1.13°C to 3.66°C in 2060s and 1.30°C to 4.68°C in 2080s.

The precipitation projection exhibited an increase in average mean precipitation in periods (2020s, 2040s ,2060s and 2080s). As can be shown in Figure below, in all periods there may be a decrease in precipitation for months May & September and increase in all other months for both scenarios (4.5rcp and 8.5rcp). The overall effect in 2020s may be an increase of average annual precipitation by 6.85mm in the 4.5rcp scenario and 1.57mm in the 8.5rcp scenario.

In 2080s the overall effect may be an increase of average annual precipitation by 9.88mm in the 4.5 scenario and 18.34mm in the 8.5 scenario.

# 3.3 Aquacrop Model Results

# 3.3.1 Calibration and Uncertainty Analysis

Crop simulations were based on the cultivar N-14, which occupied 28% of the sugarcane area at Wonjishoa during the 2015/2016 season. Calibration of the model to this cultivar was done using the field data obtained in wonji shoa. Model performance was evaluated using index of agreement, root mean square error (RMSE) and the coefficient of determination (R2)

AquaCrop calibration; The simulations performed focused on total biomass and yields. Trough repeated simulation runs and output comparison (biomass and grain yields) of simulated versus observed yields, a set of values were arrived at for conservative parameters which seemed most appropriate and gave satisfactory results for the period of 1990–2006. Model validation for validation, data from 2007–2016 were used. There was a good fit between the simulated aboveground biomass and grain yield agreed well with their corresponding observed data for all treatments during successful seasons had better fit (R2 = 0.89).

# 3.3.2 Climate Change Impact on Sugarcane Evapotranspiration

Aquacrop produced by using downscaled climate data (Tmax and Tmin) and location (altitude, latitude) data of wonjishoa for future time period. In the 2020s for the 4.5 rcp scenario, the Eto show increasing in about 121.13mm and for 8.5rcp scenarios by 293.08mm. In period of 2040s the same trained continue that increases in 4.5rcp by 168.24mm and, for 8.5rcp an increase up to 390.08mm is observed. In 2060s for both scenarios there is an Increase Eto by 190.3mm for 4.5rcp and 448.3mm 8.5rcprespectively. In the 2080s increasing of Eto is there for both scenario having the value of 228.44 mm and 461.3mm respectively.

# 3.3.3 Climate Change Impact on Sugarcane Irrigation Requirement

For the irrigated sugarcane crop, the climate impact on irrigation amounts was assessed, assuming same future yields. To meet that yield the assigned water for production give us the clue about irrigation requirement. The difference in irrigation application between the base line scenario and future with the same yield present here. In the 2020s for the 4.5 rcp scenario, the irrigation requirement shows any decreasing or increasing trends for successive four benchmarks. For 8.5rcp scenarios irrigation requirement show decreasing starting from 2060s. In 2060s requirement decreases by 5.22mm and in the 2080s decreasing of irrigation requirement reach value of 62.4mm.

## 3.3.4 Climate Change Impact on Sugarcane Yields

Climate change impact on sugarcane yield was analyzed by comparing baseline yield and future yield for the 2020s, 2040s ,2060s and 2080s.In the 2020s for both scenario, the yield show increasing in about 2.80ton/ha and 3.12ton/ha for 8.5rcp respectively. In period of 2040s the same trained continue that increases in 4.5rcp by 2.96 ton/ha and, for 8.5rcp up to 3.13 ton/ha is observed. In 2060s for both there is Increase in yield both for 4.5rcp and 8.5rcp by 3.11ton/ha and3.22 tons/ha respectively. In the 2080s increasing of yield is there for both scenario having the value of 3.02ton/ha and 3.32ton/ha respectively.

## 3.3.5 Climate Change Impact on Sugarcane Biomass

Climate change impact on sugarcane biomass was analyzed by comparing baseline biomass and future biomass yield for the 2020s, 2040s ,2060s and 2080s. In the 2020s for the 4.5 rcp scenario, the biomass show increasing in about 14.01ton/ha and for 8.5rcp scenarios by 15.60ton/ha. In period of 2040s the same trained continue that in 4.5rcp by 14.77ton/ha and, for 8.5rcp up to 15.3 ton/ha is observed. In 2060s also for both scenarios there is Increase in biomass production that, for 4.5rcp 15.56ton/ha and 8.5rcp by and16.13 tons/ha respectively. In the 2080s increasing of biomass production is there for both scenario having the value of 15.3ton/ha and 16.61ton/ha respectively.

## 3.4 Uncertainties in the Study

There are various sources of uncertainties climate change impact assessment works. The uncertainties for this study results from GCM outputs and Problem related to Aquacrop model development. Unavoidably, the approach developed in this study which has linked climate scenarios and crop modeling has limitations. This study does not take into account the possibility of future change in daily rainfall distribution within the seasons, or changes in the frequency of extreme events such as droughts, heat waves or cloudiness, which could substantially change the results discussed here. Climate scenarios have many uncertainties including that, in the future projections of climate generally stem from uncertainties in defining the factors (e.g. population growth, economic growth and development, energy use, control measures, transfer of clean technology to developing countries) that affect future emissions scenarios. Converting these emissions to atmospheric concentrations of the relevant greenhouse gases is also problematic.

Any or all of the above uncertainties may cause the results to deviate from reality. Hence great care should be taken in interpreting the result by taking into account all these uncertainties.

# 4. Conclusion

In this study, the impact of climate change on the crop yield and irrigation requirement is assessed based on projected climate conditions by using downscaled RCM out puts of CORDEX for both medium and high (4.5rcp and 8.5rcp) scenarios with AQUACROP model. For WonjiShoa plantation estate, the average annual minimum temperature in 2020s will be increased by 1.35°C and 1.59°C for 4.5rcp and 8.5rcp scenario respectively. For the 2040s periods the average annual minimum temperature will be increased by 1.79°C and 2.7°C for 4.5rcp and 8.5rcp scenario respectively. For the 2060s periods the average annual minimum temperature will be increased by 2.59°C and 3.63°C for 4.5rcp and 8.5rcp scenario respectively. For the late 21 centuries the average annual minimum temperature will be increased by 2.79°C and 4.09°C for 4.5rcp and 8.5rcp scenario respectively. The result from the downscaled annual temperature and precipitation changes showed that the climate in the WonjiShoa area will generally become warmer and wetter in each scenario. The possible range of climate change conditions were translated to link with Aquacrop to predict impact analysis.

In addition to fluctuations on temperature and precipitation, population growth is among current trends Estate. The shallow ground water at the place is also one another problem at the site so, further study connecting the climate change, ground water and production may have held.

# Declarations

**Author Contributions:** B.A. conceived and developed the research framework. T.D., M.A, and S.E undertook the data processing and analysis. T.D., B.A., and S.E. wrote and revised the manuscript. M.A. supervised and revised the manuscript. All authors have read and agreed to the published version of the manuscript.

**Conflicts of Interest:** The author declares no conflict of interest.

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**Availability of data and material**

All data generated and analyzed during this study are included in this published article.

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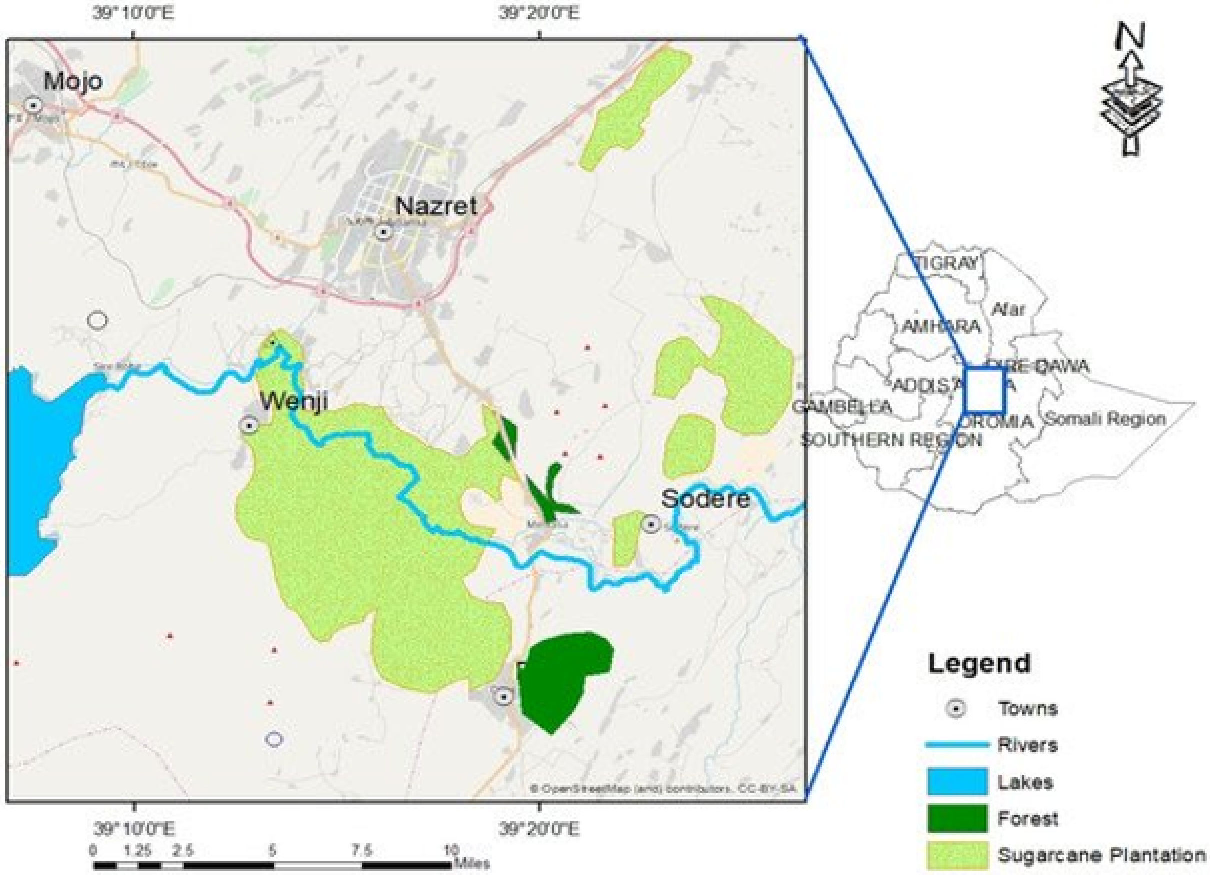
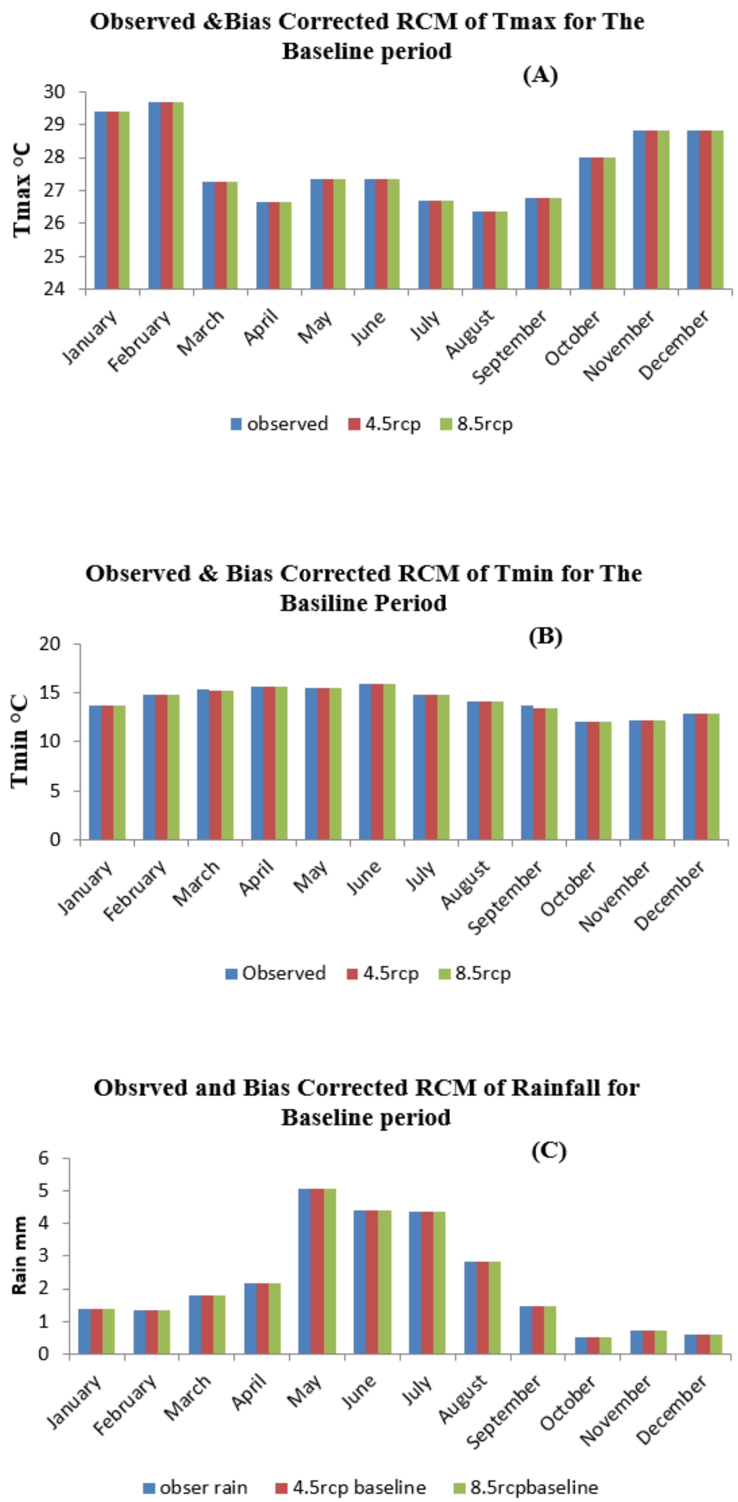
# Figures




## Figure 1

Location Map of the Study Area




## Figure 2

observed and bias corrected RCM monthly mean (A) Tmax, (B) Tmin and (C) precipitation for baseline period

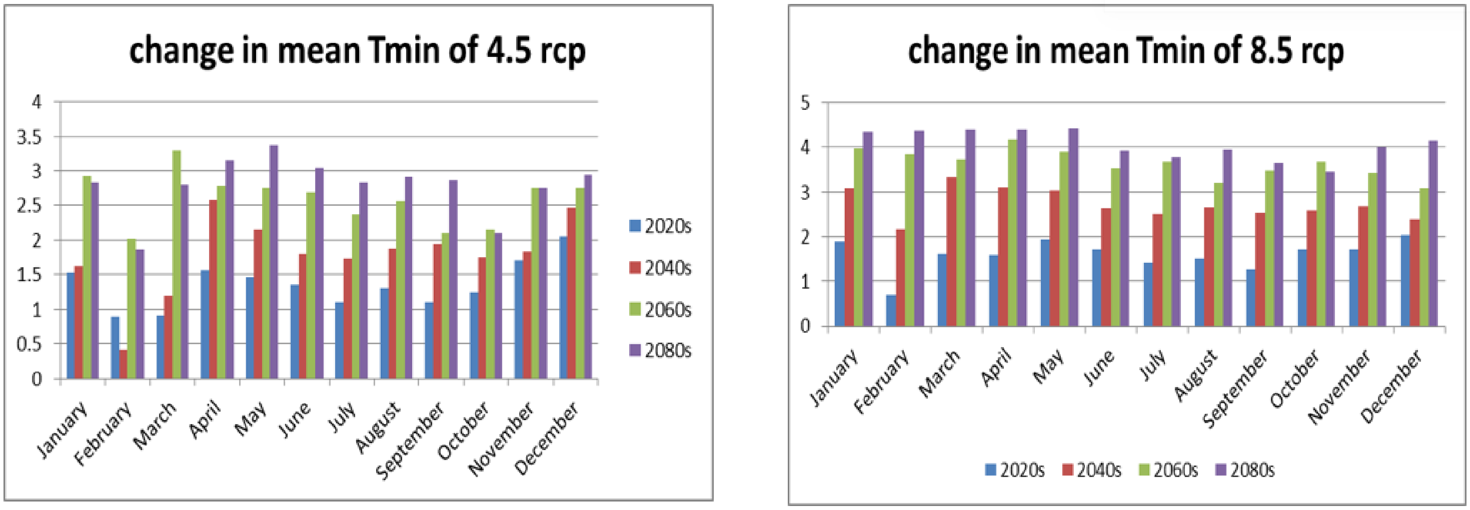



**Figure 3**

Change in Tmin(2011-2099) at wonjishoa for both scenarios

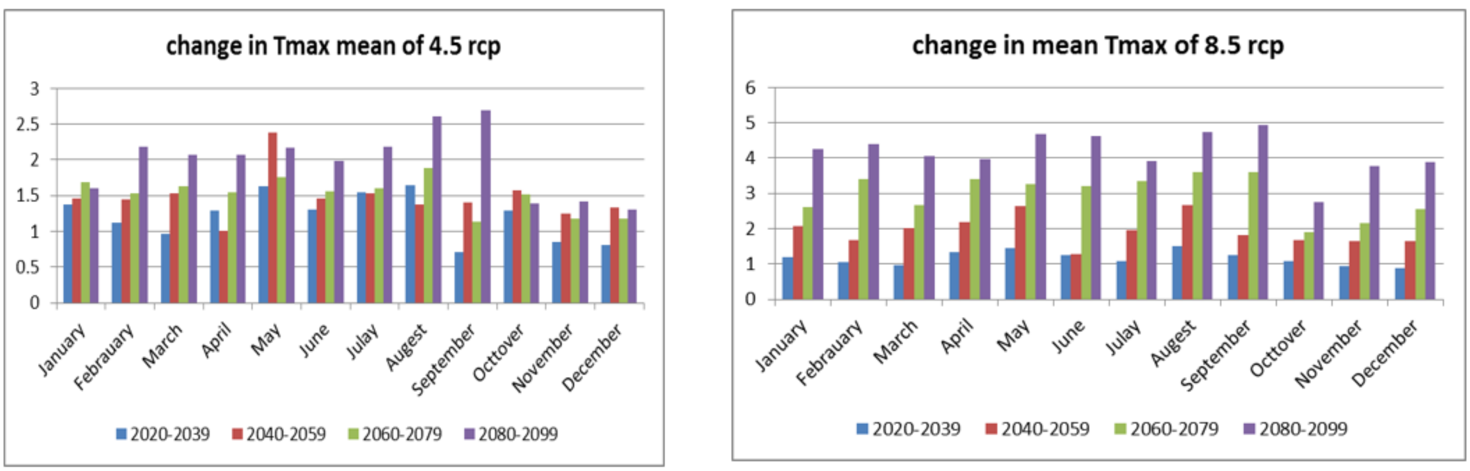
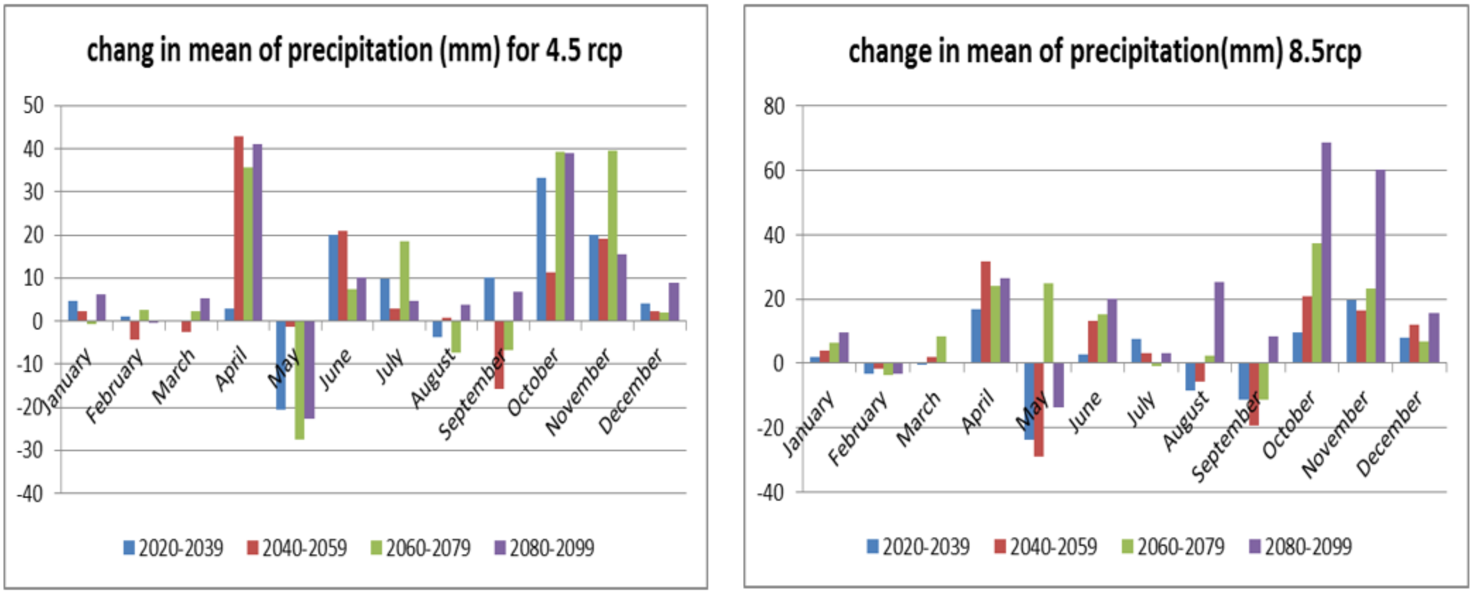


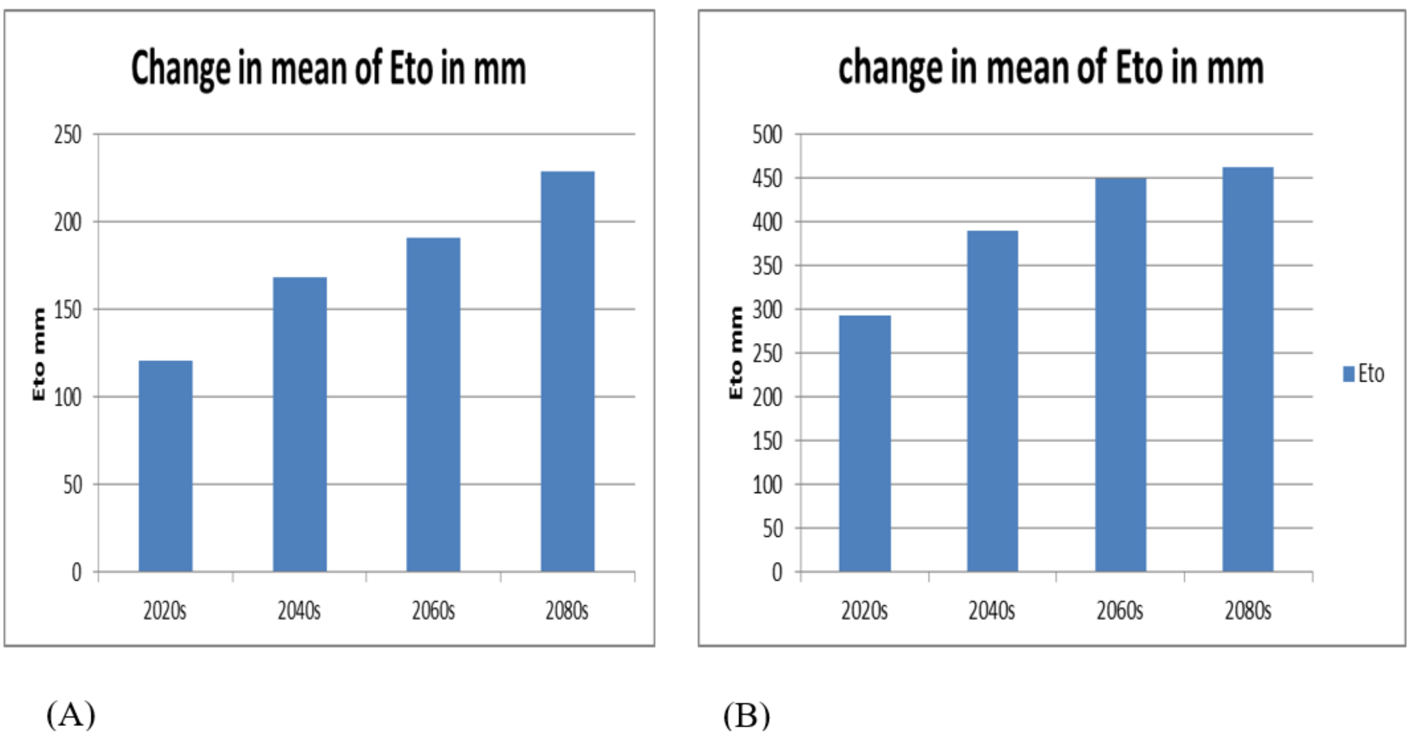

**Figure 4**

Change in Tmax (2011-2099) at wonjishoa for both scenarios




## Figure 5

change in mean of precipitation at WonjiShoa for both Scenarios




## Figure 6

Average mean change of Eto for (A) 4.5 rcp scenario (B) 8.5 rcp scenario