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# Statistical downscaling (Delta method) of precipitation and temperature for Bilate watershed, Ethiopia

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**It is important to investigate potential changes in temperature and precipitation for assessing the impacts of future climate change on agricultural production for specific regions. In this study, climate scenarios of precipitation and temperature for the bilate watershed were generated. Statistical downscaling techniques of the Delta method analysis protocol of the Agricultural Intercomparison and Improvement Project (AgMIP) was used to project the future climate state in the farm lands of Bilate Watershed. In this study, climate change scenarios were generated for two Representative Concentration Pathways (RCPs): RCP 4.5 and RCP 8.5 using 20 GCMs from CMIP5 bias-corrected under three future time slices; near-term (2010-2039), mid-century (2040-2069) and end-century (2071-2099). Rainfall is projected to increase in total amount under all-time slices and emissions pathways but with pronounced inter and intra-variability. Minimum temperature will significantly increase during mid-century by 1.81°C (RCP 4.5) and 2.55°C (RCP 8.5) and by 2.1°C (RCP 4.5) and 4.27°C (RCP8.5) during end-century relative to the baseline. The projected increase in maximum temperature during mid-century is 1.43°C under RCP 4.5 and 1.99°C under RCP 8.5 and during end-century by 1.65°C under RCP 4.5 and 3.5°C under RCP8.5 during end-century.**

**Key words:** Agricultural Intercomparison and Improvement Project (AgMIP), climate change, Delta method, Global climate models (GCMs), statistical downscaling, watershed.

## INTRODUCTION

The issue of climate change and its impacts on a global scale are the focus of strong, wide international research efforts in natural and social sciences. However, understanding the nature and potential consequences of climate change at regional scales remains a challenge (El-Jabi et al., 2013). To make estimates of the future climate, the climate change research community needs to address three different questions: How will emission rates change in the future, how the climate will respond to such changed emissions and how large is the climate variability irrespective of changing emissions (Ekström et al., 2015). Observed changes in the Earth's climate over

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the past ~ 250 years are now widely considered to have been enhanced by anthropogenic activity (IPCC, 2007) and Global climate models (GCMs) are the typical tools used to simulate the response to increasing concentrations of human-induced GHGs (Ekström et al., 2015). Several Global Climate Models(GCMs) have been developed to simulate global climatology including precipitation and multiple GCMs that have been used to simulate historic climate and project future climate based on different Emission scenarios (IPCC, 2007; Swain et al., 2014). The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) states Emissions scenarios as plausible trajectories of different aspects of the future that are constructed to investigate the potential consequences of anthropogenic climate change. Scenarios represent many of the major driving forces-including processes, impacts (physical, ecological, and socioeconomic), and potential responses (IPCC, 2013).

Global Climate Models (GCMs) are the best tools to estimate future global climate changes resulting from greenhouse gas concentration with different Emission scenarios in the atmospheres (Dibike and Coulibaly, 2005; Cheng et al., 2012). However, due to their coarse spatial resolution, the outputs from these models may not be used directly in impact studies. Hydrological models, for instance, deal with small or sub-catchment-scale processes whereas GCMs simulate planetary-scale and parameterize many regional and smaller-scale processes. Therefore, there is a scale mismatch between GCMs and hydrological models and these needs downscaling of GCMs to catchment or sub-catchment process (Coulibaly et al., 2005; Chen et al., 2012, 2013). So one of the important issues for the analysis of climate change impact is the part related to the downscaling of GCM data and the studies on downscaling techniques had arisen from the issue on the resolution of GCM (Kim et al., 2014). Several downscaling methodologies have been developed to transfer the GCM simulated information to a local scale. In general, the local scale is defined based on geographical or physiographic considerations (Anandhi et al., 2008; Bhattacharjee and Zaitchik, 2015). The objective of this study is to statistically downscale and produce future climate scenarios under different representative pathways for Bilate watershed.

## MATERIALS AND METHODS

### Description of study area

Bilate is one of the inland rivers of Ethiopia that drains the northern watershed of Lake Abaya-Chamo Drainage Basin which forms part of the Main Ethiopian Rift and in turn is part of an active rift system of the Great Rift Valley. The Bilate River Watershed (BRW) covers an area of about 5625 km$^2$ and is located in the southern Ethiopian Rift Valley and partly in the Western Ethiopian Highlands (Figure 1). The altitude of the watershed ranges from 1300 at Lake Abaya to 3050 meters above sea level at Mt. Ambaricho. Geographically, its absolute location, south-north extends from 6º 36'N 38º00'E at Lake Abaya Wolaita Zone SNNPR to 8º05'N 38 º12'E at Gurage and Silte Zones border, SNNPR. On the other hand its west-east extension is from 7º18'N 46'E at Kambata Zone to 7º12'N38º22'E Sidama Zone.

The mean annual rainfall in the BRW ranges between 721 and 1353 mm which shows large spatial variability with maximum rainfall is as large as 1.87 times the minimum rainfall. Areas that belong to the part of the Western Ethiopian Highlands show higher rainfall on an annual base while the part of the watershed that belongs to the Ethiopian rift valley shows lower rainfall. Based on the interpolation method used, the mean annual rainfall of the period 1984 to 2013 is estimated to be 1121 mm.

The station time series rainfall data was obtained from the Ethiopian National Meteorological Agency (NMA) for the period of Jan/01/1980 to Dec/31/2013. The hydromet stations having more than 75% of daily rainfall data were selected for this study. From the available stations, only 11 stations satisfied the criteria. The selected stations with their mean annual value and the percent of daily missing rainfall data for the 30 years period under study is summarized in Table 1.

The pattern of daily maximum temperature is more or less the same in all the stations, where the highest values of the daily maximum temperature are observed in February and March which are the dry period of the area. The lowest value of maximum temperature is recorded in July and August. Unlike the daily maximum temperature, it is not easy to draw a trend of daily minimum temperature for the selected stations. Relatively, Hosana station shows the smallest minimum temperature value on average, whereas Bilate shows the highest value. These show the dependence of temperature on elevation as these two stations are the highest and lowest level respectively.

### Modeled climate dataset

The station observations of daily rainfall, maximum and minimum temperatures (Table 2) from 1980 to 2010 were statistically downscaled using the Delta Method developed by the Agricultural Model Intercomparison and Improvement Project (AgMIP) to produce climate scenarios.

The wind speed and relative humidity at the time of maximum temperature daily were retrieved from the AgMIP climate forcing dataset based on the NASA Modern-Era Retrospective Analysis for Research and Applications (MERRA). These datasets are stored at 0.25×0.25° horizontal resolution (~25 km), with global coverage and daily values from 1980 to 2010 to form a "current period" climatology (Ruane et al., 2015).

The data of 20 models (ACCESS1 -0, bcc-csm1-1, BNU-ESM, CanESM2, CCSM4, CESM1-BGC, CSIRO-Mk3-6-0, GFDL-ESM2G, GFDL-ESM2M, HadGEM2-CC, HadGEM2-ES, inmcm4, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC5, MIROC-ESM, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, and NorESM1-M) from the Coupled Multi-model Intercomparison Project Phase 5 (CMIP5) ensemble and embedded in AgMIP protocol were provided by the AgMIP climate team from the NASA Goddard’s online File Depot (Table 3).

### Downscaling model description

The term ‘statistical downscaling’ typically comprises techniques that use empirical relationships between local-scale variables and large-scale atmospheric variables (Ekström et al., 2015). It creates empirical relationships between historical large-scale atmospheric and local climate characteristics. Once a relationship has been determined and validated, future large-scale atmospheric conditions

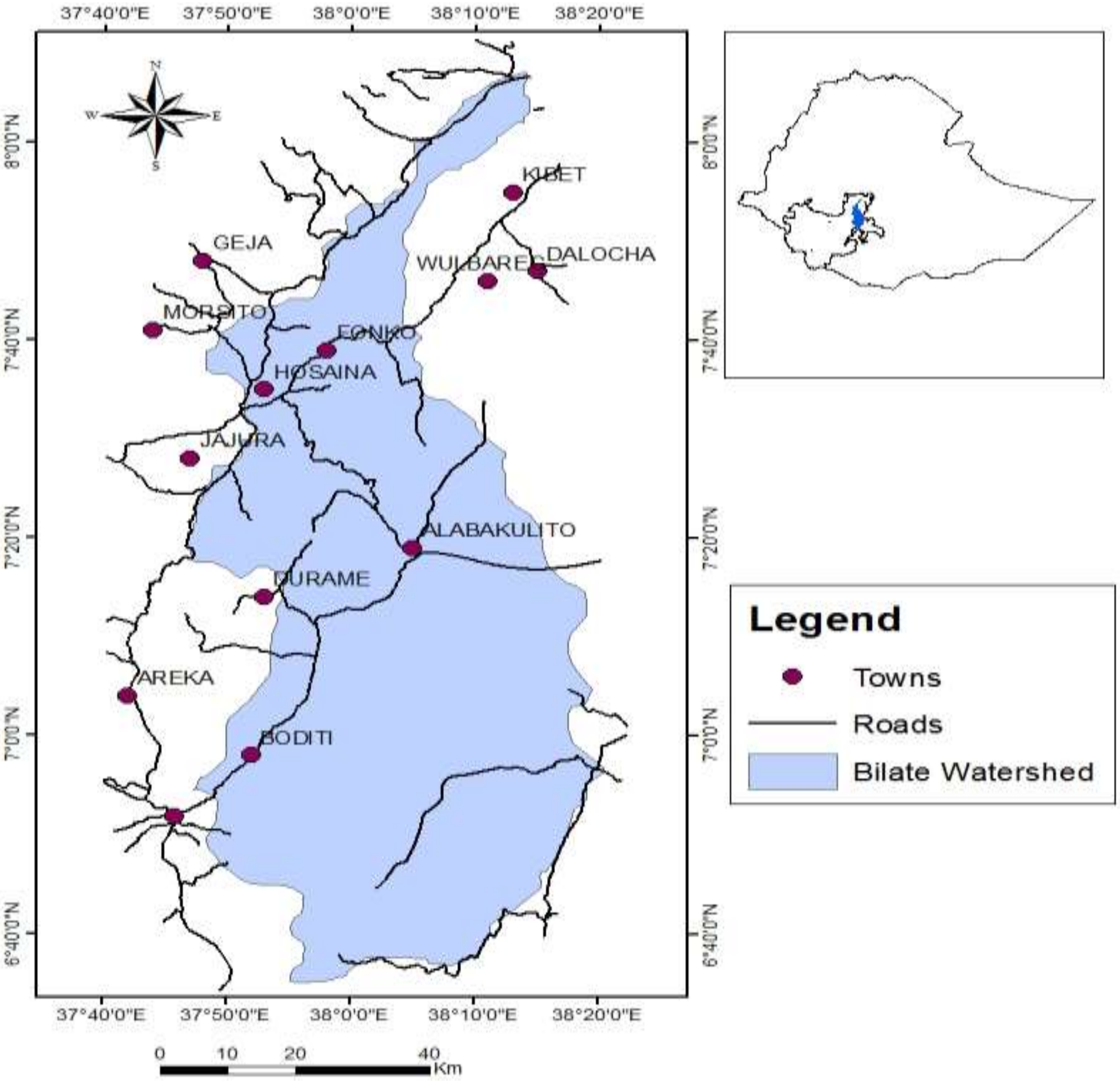


**Figure 1.** The Location map of the Bilate River Watershed.

projected by GCMs are used to predict future local climate characteristics (Von Storch et al., 2000; Fowler et al., 2007; Maraun, 2010; Trzaska and Schnarr, 2014). In situations where a low-cost, rapid assessment of highly localized climate change impacts is required, statistical downscaling represents the more promising option (Wilby et al., 2002).

The Delta method is a statistical downscaling procedure that is based on the sum of interpolated anomalies to high-resolution monthly climate surfaces. The method produces a smoothed (interpolated) surface of changes in climates (deltas or anomalies) and then applies this interpolated surface to the baseline climate, taking into account the possible bias due to the difference in baselines (Ramirez-Villegas and Jarvis, 2010). In this study the Delta method analysis protocol of the Agricultural Intercomparison and Improvement Project (AgMIP) was used to project the future climate state in the farm lands of Bilate Watershed (Rosenzweig et al., 2013).

The method makes the following two gross assumptions; first "Changes in climates vary only over large distances (that is, as large as GCM side cell size)" second, "Relationships between variables in the baseline ('current climates') are likely to be maintained towards the future". But these assumptions might not hold true in heterogeneous landscapes, where topography could cause variations in anomalies (Ramirez-Villegas and Jarvis, 2010). To overcome the shortcomings in the assumptions the method was applied to three sites (Hosana, Alaba Kulito and Bilate) representing and covering relatively homogeneous areas in the upper, middle and lower courses of the watershed respectively.

### Emission scenarios

The past climate variation is highly driven by the changes in external forcing, thus to "predict" the climate of the 21st century and beyond, it is necessary to estimate future changes in the forcing. And this is achieved by the development of scenarios for the emission of greenhouse gases, aerosols, various pollutants in the atmosphere, land use, etc. (Goosse et al., 2010). Among the

**Table 1.** Gauging stations in the Bilate River Watershed (BRW).

| S.N | Station name | Easting (m) | Northing (m) | Altitude (m) | Missing daily % | Mean annual rainfall (mm) |
|---|---|---|---|---|---|---|
| 1 | Alaba Kulito | 399982.7 | 808180.6 | 1772 | 0.74 | 1025 |
| 2 | Angacha | 373864.6 | 811557.1 | 2317 | 17.82 | 1223 |
| 3 | Bilate | 398710.0 | 753578.3 | 1361 | 6.03 | 781 |
| 4 | Boditi | 384561.1 | 768748.2 | 2043 | 1.97 | 1154 |
| 5 | Durame | 384070.2 | 795991.4 | 2000 | 5.16 | 1031 |
| 6 | Fonko | 386177.6 | 844881.6 | 2246 | 9.17 | 1093 |
| 7 | Hosana | 373561.7 | 836620.6 | 2307 | 3.74 | 1100 |
| 8 | Imdiber | 382787.9 | 897533.5 | 2082 | 8.19 | 1068 |
| 9 | Mayokote | 373280.0 | 761280.2 | 2121 | 22.29 | 1173 |
| 10 | Shone | 384327.0 | 773908.4 | 1959 | 1.72 | 1353 |
| 11 | Wulbareg | 402990.4 | 855255.7 | 1992 | 3.69 | 1131 |

**Table 2.** Selected meteorological stations in the Bilate Watershed.

| Station name | Longitude | latitude | Altitude (m) | Data range (year) | Missing % |
|---|---|---|---|---|---|
| **Maximum and minimum temperature** | | | | | |
| Alaba Kulito | 38.09 | 7.31 | 1772 | 1980-2013 | 6.16 |
| Bilate | 38.08 | 6.82 | 1361 | 1980-2013 | 14.86 |
| Hosana | 37.85 | 7.57 | 2307 | 1980-2013 | 17.79 |
| **Rainfall** | | | | | |
| Alaba Kulito | 38.09 | 7.31 | 1772 | 1980-2013 | 0.74 |
| Bilate | 38.08 | 6.82 | 1361 | 1980-2013 | 6.03 |
| Hosana | 37.85 | 7.57 | 2307 | 1980-2013 | 3.74 |

number of possible alternative futures, until the fourth assessment report of the IPCC, the climate projections were based on the Special Report on Emission Scenarios (SRES) scenarios (IPCC, 2000). During the IPCC Fifth Assessment Report a new set of scenarios, the Representative Concentration Pathways (RCPs), was used for the new climate model simulations carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme (IPCC, 2013). A set of four RCPs were selected. RCP3-PD (peak and decline), the radiative forcing peaks before 2100 at about 3 $Wm^{-2}$ and then declines. RCP6.0 and RCP4.5 are characterized by a steady rise during the 21st century, up to a radiative forcing of about 6 and 4.5 $Wm^{-2}$ respectively, and stabilization after 2100. Finally, the most extreme one, RCP8.5 displays a continuous rise in radiative forcing during the 21st century, leading to a value of about 8.5 W $m^{-2}$ in 2100 (Goosse et al., 2010; van Vuuren et al., 2011; IPCC, 2013).

In this study climate change scenarios were generated for two Representative Concentration Pathways (RCPs): RCP 4.5 and RCP 8.5 using 20 GCMs from CMIP5 bias-corrected under three-time slices, near-term (2010-2039), mid-century (2040-2069), and end-century (2071-2099). RCP 4.5 describes the medium stabilization scenario without overshoot pathway and RCP 8.5 describes rising radiative forcing pathway leading to a very high emissions scenario (Van Vurren et al., 2011). In the analysis, both concentration pathways in all three periods were applied and the analysis was performed with the built-in AgMIP Climate scenario Generation Tools with the R software environment.

### Description of GCMs used

AgMIP protocols emphasize the use of multiple models because ensembles allow better characterization of the uncertainty associated with model outputs (Cheryl et al., 2014). So, the future climate scenarios are based upon the observed baseline climate and changes simulated by an ensemble of general circulation models (GCMs) from the Fifth Coupled Model Intercomparison Project (CMIP5). CMIP5 is meant to provide a framework for coordinated climate change experiments for the IPPC AR5 and beyond and it promotes a standard set of model simulations to provide projections of future climate change on two-time scales, near term (out to about 2035) and long term (out to 2100 and beyond).

### Generation of climate scenario

Future climate scenario is generated for precipitation and minimum and maximum temperature for three stations of the study area

**Table 3.** List of the global climate models in CMIP5 used in the study.

| Model name | Modelling centre (or group) | Spatial resolution (longitude*latitude) |
|---|---|---|
| ACCESS1.0 | Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia | 192*145 |
| BCC-CSM1.1 | Beijing Climate Centre, China Meteorological Administration | 128*64 |
| BNU-ESM | College of Global Change and Earth System Science, Beijing Normal University | 128*64 |
| CanESM2 | Canadian Centre for Climate Modelling and Analysis | 128*64 |
| CCSM4 | National Centre for Atmospheric Research | 288*192 |
| CESM1(BGC) | Community Earth System Model Contributors | 288*192 |
| CSIRO-Mk3.6.0 | Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence | 192*96 |
| GFDL-ESM2G | NOAA Geophysical Fluid Dynamics Laboratory | 144*90 |
| GFDL-ESM2M | | |
| HadGEM2-CC | Met Office Hadley Centre | 192*145 |
| HadGEM2-ES | | |
| INM-CM4 | Institute for Numerical Mathematics | 180*120 |
| IPSL-CM5A-LR | Institut Pierre-Simon Laplace | 96*96 |
| IPSL-CM5A-MR | | 144*142 |
| MIROC-ESM | Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies | 128*64 |
| MIROC5 | Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology | 256*128 |
| MPI-ESM-MR | Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology) | 192*96 |
| MPI-ESM-LR | | |
| MRI-CGCM3 | Meteorological Research Institute | 320*160 |
| NorESM1-M | Norwegian Climate Centre | 144*96 |

which is known to represent the upper, middle and downstream of the watershed. The Delta method statistical downscaling under the Representative concentration Pathways RCP 4.5 and RCP 8.5 from ensemble of 20 GCMs was used for building future climate scenario. Climate scenarios from Fifth Coupled Model Intercomparison Project (CMIP5) GCMs using 30 year (1980-2009) baseline daily weather data is generated by the AgMIP Climate Scenario Generation Tool with R climate scripts.

The three stations considered for the statistical downscaling are of tens to few hundred kilometres apart from each other within the watershed that resulted in no significant difference in the trend of the future climate scenarios generated, even though there was an initial assumption that topography could cause considerable variations in anomalies. As a result, the Alaba Kulito station was used for depicting the trend and nature of future climate scenario in the Bilate watershed considering four scenario periods: The base period or historical-time (1980-2009), the near-term (2010-2039), mid-century (2040-2069) and end-century (2070-2099).

## RESULTS AND DISCUSSION

### Projected temperature

All the 20 models showed a similar trend in the projected maximum and minimum temperature in both representative concentration pathways in the whole 21$^{st}$ century. The mean result of the ensemble of all 20 models was shown in Table 4. The Downscaled results of minimum and maximum

**Table 4.** Projected temperatures in the Alaba Kulito area**.**

| Analysis time slice | Projected temperature (°C) | |
|---|---|---|
| | RCP 4.5 | RCP 8.5 |
| **Near time (2010-2039)** | | |
| Tmax | 28.39 + 2.75 | 28.43 + 2.73 |
| Tmin | 11.89 + 4.50 | 12.03 + 4.50 |
| **Mid-century (2040-2069)** | | |
| Tmax | 29.09 + 2.73 | 29.65 + 2.70 |
| Tmin | 12.74 + 4.49 | 13.48 + 4.49 |
| **End-century (2070-2099)** | | |
| Tmax | 29.31 + 2.69 | 31.16 + 2.65 |
| Tmin | 13.03 + 4.50 | 15.20 + 4.47 |

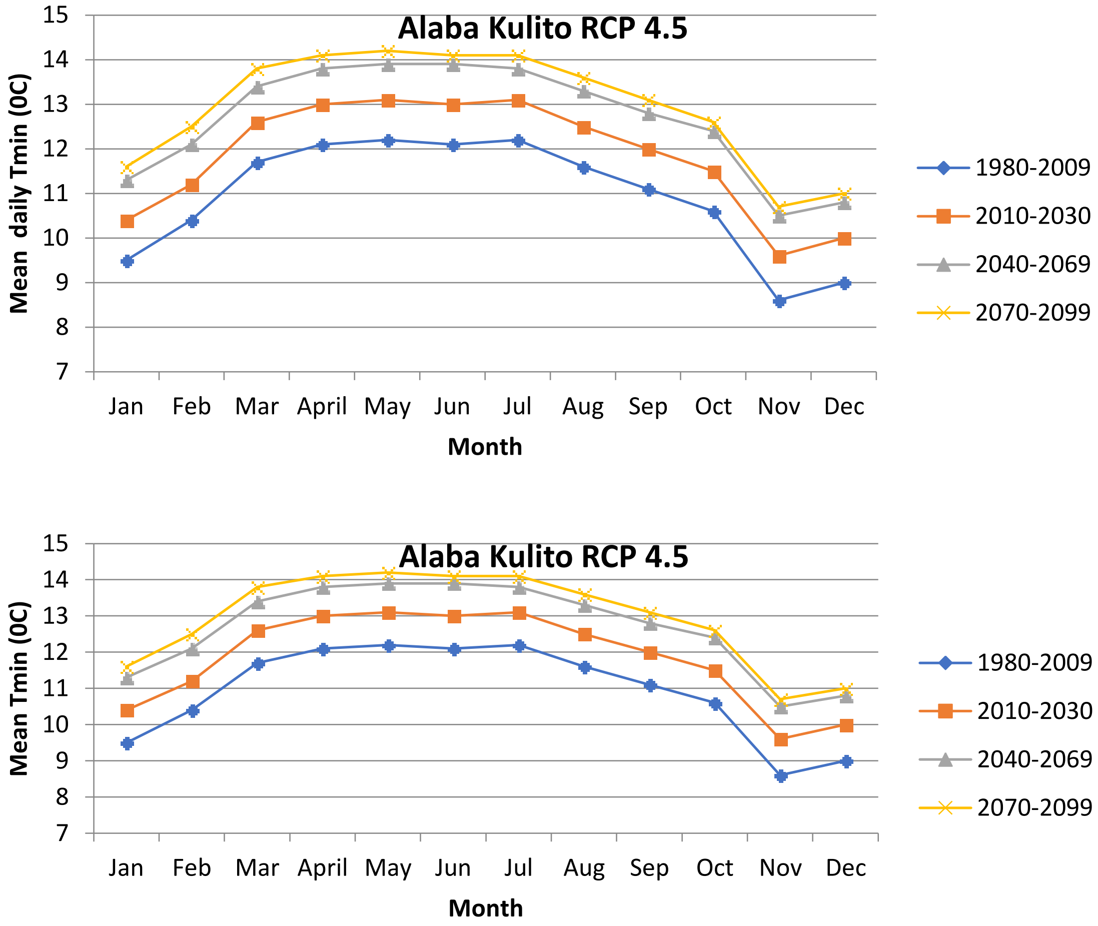
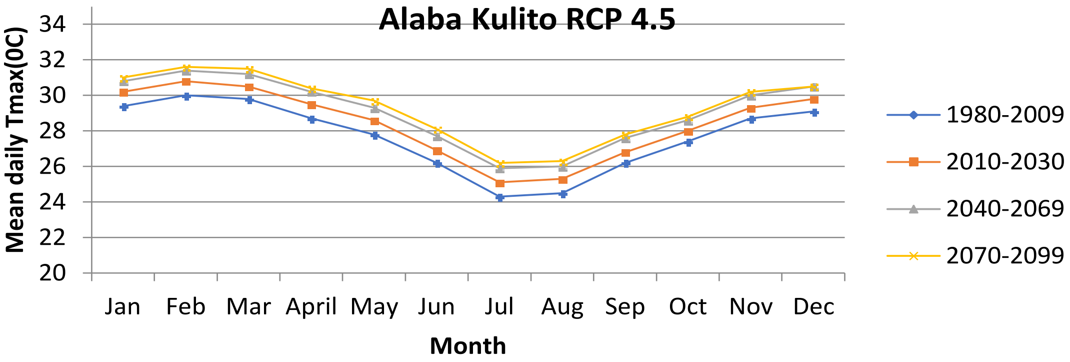


**Figure 2.** Trends of daily minimum temperature at Alaba Kulito under RCP 4.5 and RCP 8.5.

temperature at Alaba Kulito are shown in Figures 2 to 4. Both scenarios show an increasing trend of minimum and maximum temperature where RCP 8.5 slightly overestimates compared to RCP 4.5. The average



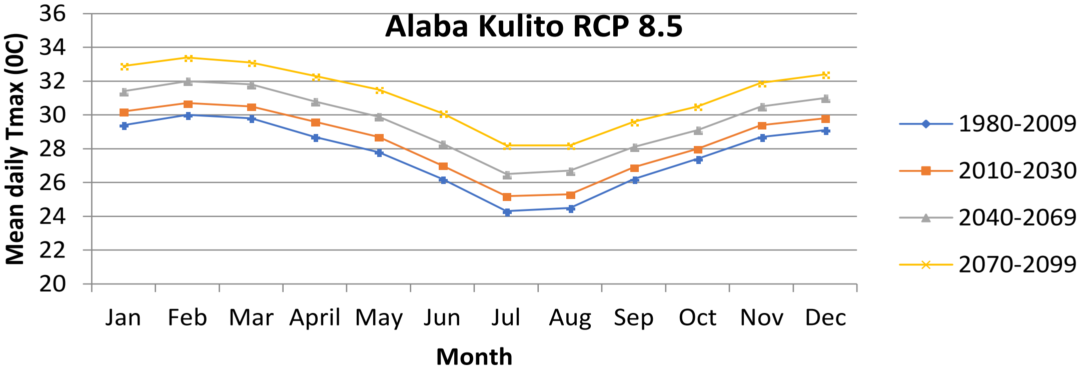


**Figure 3.** Trends of daily maximum temperature at Alaba Kulito under RCP 4.5 and RCP 8.5.

maximum temperature (27.66°C) of the base years (1980-2009) increases by 1.65 and 3.5°C by the end of the 21st century under RCP 4.5 and RCP 8.5 respectively. From the same statistics for data downscaled in both Representative Concentration Pathways the average minimum temperature (10.93) of the base year shows an increase of 2.1 and 4.27°C for RCP 4.5 and RCP 8.5 respectively by the end of the 21st Century. This result of the increase in minimum and maximum temperature is in agreement with the IPCC Fifth Assessment Report (Niang et al., 2014).

There will be consistency in the rising trend of minimum temperature under both RCP 4.5 and RCP 8.5 but with a sharper rise under RCP 8.5 leading to an increasing gap between the two emissions pathways. This can be explained by continued rising emission concentrations that the fifth assessment report (AR5) has shown will continue rising (RCP 4.5 near-term 423 ppm, mid-century 499 ppm, and end-century 532 ppm) (Stocker et al., 2013).Progressive rise in maximum temperature under both representative concentration pathways during the mid-century and a sluggish rise under RCP 4.5 at the end century will be experienced. The projected increase in both minimum and maximum temperature over the farmlands of the Bilate watershed will end up in warming, attributed to be a direct effect of the continued increase in carbon dioxide emissions during the 21st century and it is in agreement with the findings that have shown that there will be warming over East Africa (Waithaka et al., 2013).

## Projected rainfall

The results of the projection of the mean ensemble of all 20 models show rainfall Variability within and between time-slices as well as in different scenarios will generally remain high (Table 5). The high standard deviations of the results also show that spatial and temporal variability within and between locations in both scenarios will be expected. Hosana is the only area that will experience an overall rainfall decline under RCP 4.5 in near-term but return to a positive average during mid-century (2040-2069) and end-century (2070-2099). Notably, under an all-time period, projected total rainfall will be higher under the RCP 8.5 scenario (Table 5).

For the farmlands near Alaba Kulito, the mean ensemble of all 20 models showed a similar pattern of rainfall in the all-time period (Near term 2010-2039, midcentury 2040-2069, and end-century 2070-2099). The mean annual rainfall for the total projection period (2010-

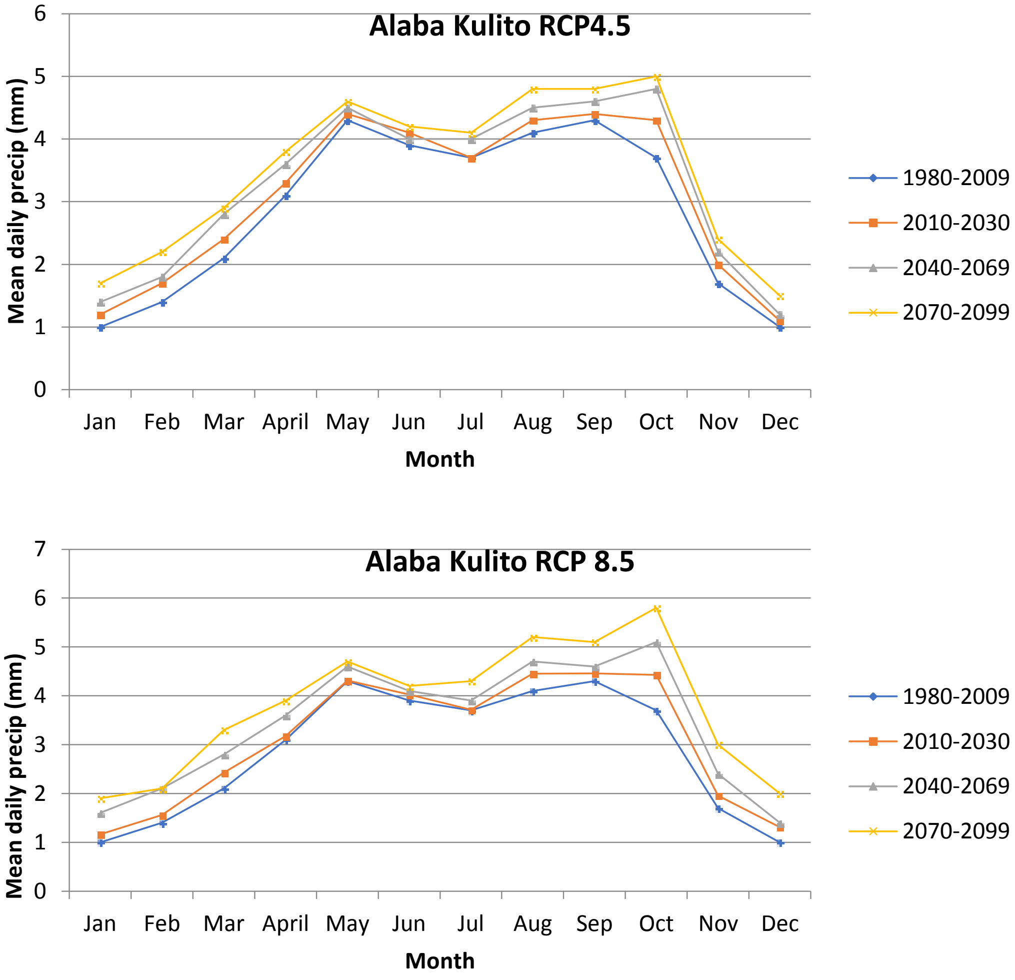


**Figure 4.** Trends of precipitation at Alaba Kulito station under RCP 4.5 and RCP 8.5.

**Table 5.** Projected rainfall in farm lands of Bilate Watershed**.**

| Analysis time slice | Projected mean annual rainfall (mm) | |
|---|---|---|
| | **RCP 4.5** | **RCP 8.5** |
| **Near term (2010-2039)** | | |
| Alaba Kulito | 1124.87 ± 161.60 | 1129.83 ±161.32 |
| Bilate | 827.37 ± 112.36 | 832.5 ± 113.15 |
| Hosana | 1081.09 ± 171.33 | 1078.52 ± 170.44 |
| **Mid-century (2040-2069)** | | |
| Alaba Kulito | 1201.91± 174.57 | 1243.16 ± 182.30 |
| Bilate | 892.45 ± 123.29 | 923.61 ±131.37 |
| Hosana | 1136.43 ± 181.46 | 1160.97 ± 187.09 |
| **End-century (2070-2099)** | | |
| Alaba Kulito | 1282.13 ± 188.40 | 1384.58 ± 208.52 |
| Bilate | 940.52 ± 134.65 | 1047.59 ± 151.56 |
| Hosana | 1179.32 ± 193.70 | 1265.08 ± 208.25 |

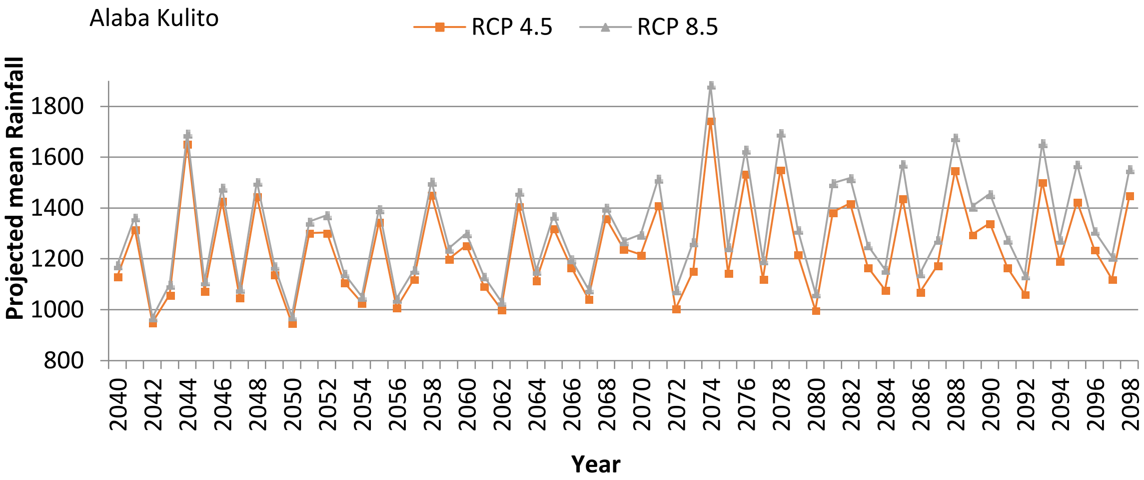


**Figure 5.** Projected total rainfall in Alaba Kulito (2040-2099).

2099) will be 1202.97±184.86 mm under RCP 4.5 and it will be 1252.52 ± 210.85 mm under RCP 8.5 respectively. Except for a slightly higher projection of rainfall under RCP 8.5 the trend in total rainfall projection under both scenarios (RCP 4.5 and RCP 8.5) is similar (Figure 5).

The total annual rainfall for the watershed will progressively increase within and between the three periods (2010-2039, 2040-2069 and 2070-2099). This agrees with the IPCC Fifth Assessment Report (FAR) that explains CMIP5 projects likely increases in mean annual precipitation over areas of central and eastern Africa beginning the mid-21$^{st}$ century for RCP8.5 and over eastern Africa by the end of the 21$^{st}$ century there will be a wetter climate with more intense wet seasons and less severe droughts (Niang et al., 2014).

## Conclusion

In this study historical datasets from the National Meteorological Agency of Ethiopia were used to perform statistical downscaling in the Bilate Watershed by the Delta method using the AgMIP Climate Scenario Generation Tool with R. Four-time slices were selected: Base-period (1980-2009), near-term (2010-2039), mid-century (2040-2069) and end-century (2070-2099). The results from the Delta method statistical downscaling model are in agreement with the IPCC's prediction over Eastern Africa in its Fifth Assessment Report (FAR). This study has shown that projected rainfall will progressively increase in total under the two projection scenarios (RCP 4.5 and RCP 8.5) within the time slices and across the whole projection period. Projections also revealed that spatio-temporal rainfall variability will continue in the watershed with total rainfall remaining higher in areas getting higher historical rainfall compared to the downstream areas with lower historical rainfall records. However, all-temperature regimes under both RCP 4.5 and RCP 8.5 will be expected to increase during the 21$^{st}$ century.

In summary, the results of the future climate scenario generation reveal conformity with findings of some research work in Eastern Africa in the particular and global context in general. The scenario data produced is based on the sets of assumptions including the considerations in the development of representative concentration Pathways. But the results are still dependent on local dynamics of the environment that did not consider the development of the Model.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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