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Forecasting reference evapotranspiration under climate change scenario in Lake Finchaa Watershed, Ethiopia

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Abstract Forecasting the influences of climate change on hydro-climatic and agro-meteorological variables are continued and picked up extensively within the field of hydrology, climatology and agricultural water sciences. Reference Evapotranspiration (ETo) is an important agro-meteorological parameter for irrigation planning and management and highly susceptible to climate perturbation. The effects of climate change on the rate of ETo in Lake Finchaa watershed under of RCP4.5 and RCP8.5 (Representative Concentration Pathway) scenarios at the end of 2055 was investigated. The ETo under current climate condition was estimated by FAO-Penman Monteith (FAO-PM) and Hargreaves-Samani (H-S) models and used to establish the relationship between the models through regression analysis for prediction of future ETo. The signal of selected Regional Climate Models in the Coordinated Regional Climate Downscaling Experiment (RCM-CORDEX) was transferred to the observed temperature data using the change factor downscaling method. The ability of climate models in reproducing observation data was statistically evaluated and validated. The analysis result indicated that the rate of annual average ETo would be rising up to 4.42% at the end of 2055 due to the increase in temperature. The obtained result also showed that annual net rainfall deficit will increase by 77.93 mm per year in Lake Finchaa watershed for the same period. These may increase crop water requirement in the watershed and reduce the water retention and infiltration time into soil, which may lead to decline of water table level, that possibly lead to a reduction in the stream flow into Finchaa hydropower reservoir.

Keywords: Change factor, Climate Models, Downscaling, RCM-CORDEX, Water availability

Introduction

Climate change is more recognized as a thoughtful phenomenon affecting a wider range of socio-economic and agricultural development activities around the globe, including extensive environmental problems. Climate change is a significant alteration of climate in mean or variability persisting for decades or even longer either due to human activities or natural factors as per definition

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of Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2013). Change in precipitation intensity, location, time and amount, increase in air and water temperature, rise in sea level, decline in water quality and others are indicators of climate change.

Temperature is one of the primary climate variables susceptible of the prevailing climate perturbation signals on the earth. According to Intergovernmental Panel on Climate Change reports (IPCC, 2013) the global surface temperature totally increased by 0.78 ℃ in the second half of 19th century (1850 to 1900). IPCC report also projects that the average surface temperature of the earth is likely to increase by 1.5 ℃ by the end of the 21st century, compared to 1850 to1900 under all Representative Concentration Pathways (RCPs) scenario except RCP2.6. Rising in surface temperature affects all processes involved in the transfer of water between atmosphere or hydrosphere and lithosphere and leads to intensification hydrologic cycle (Bhuvandas *et al.,* 2014; IPCC, 2013; Marvel and Bonfils, 2013). It is also expected to affect evapotranspiration rate and the amount of water entering river basins resulting in dryer river basins respectively(Elbehri *et al.,* 2018; Taye and Willems, 2013).

Previous studies conducted in Blue Nile basin (Abbay basin) and its sub-basin using simulations of various GCM and RCM climate change models and downscaling methods indicated that a warming trend in both maximum and minimum temperature in the past decades and the trend will continue in the future under RCPs (RCP4.5, RCP6.0 and RCP8.5) scenarios or SRES (Special Report on Emissions Scenarios) (A1, A2, B1, B2) scenarios (Ayalew *et al.,* 2012; Gebre *et al.,* 2015; Gebre and Ludwig, 2015; Hulme *et al.,* 2001; Mekonnen and Disse, 2018; Roth *et al.,* 2018; Worku *et al.,* 2019).

Majority of the previous work in the Blue Nile Basin used GCM climate models. Therefore, there is a need to use and analyse the ability of RCM-CORDEX climate models to reproduce climate variables in the basin. Meron and her colleagues (Taye *et al.,* 2015) reviewed the importance of applying and evaluating regional climate models (RCM) based on coupled model inter-comparison project phase 5 (CMIP5) and suggested CORDEX. Compared with several regional climate change assessment projects performing downscaling over a specific region (IPCC, 2015; Nikulin *et al.,* 2012) allows international coordination and knowledge transfer between these projects and facilitates easier analysis.

Reference Evapotranspiration (ETo) is an important agro-meteorological parameter in the planning and managing of agricultural water or irrigation. It is highly susceptible to climate perturbation. Hence, it depends up on the evaporative demand of the atmosphere only. Furthermore, previous review works concluded that temperature and evapotranspiration increases simultaneously (Gebre *et al.,* 2015) and there is a need and opportunities for research advancement

(Dile *et al.*, 2018) in the upper Blue Nile river basin. The main purpose of this study was to assess the impact of climate change perturbation on reference evapotranspiration (ETo) under selected RCPs scenarios using two RCM-CORDEX climate models simulations in Lake Finchaa watershed.

Materials and methods

Description of the study area

Finchaa watershed is one of the sixteen (16) sub-basins of the Blue Nile basin (Abbay basin) and is located in the southern part of Upper Blue Nile basin at coordinate of 9°30’ to 10°00’ North and 37°15’ to 37°30’ East, in Ethiopia (Figure 1). Finchaa sub-basin covers 2082 km^2 area of land and it is where the old aged artificial Lake Finchaa is found. The watershed long year mean maximum temperature, minimum temperature and mean annual rainfall is 30.6 °C, 14.7 °C and 1306 mm respectively. The rain falls are more intense during the four rainy months of June to September(Alexander *et al.*, 2020; Geleta, 2019; Geleta and Deressa, 2020; Müller-mahn and Gebreyes, 2019).

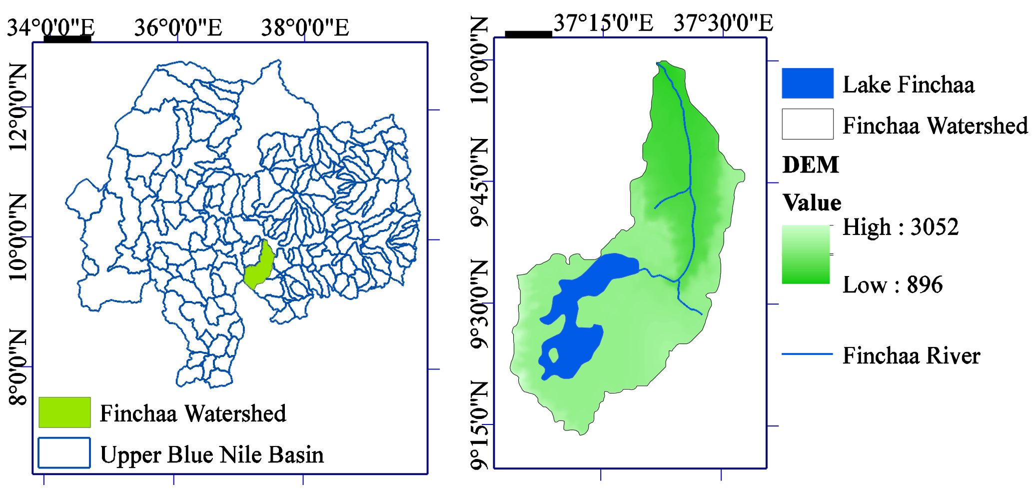

Figure 1. Location map of Finchaa Watershed and Lake Finchaa

Observed and simulated temperature

Daily observed maximum and minimum temperature data from 1981 to 2016 for the meteorological stations located in and near the study watershed were collected from the Ethiopian National Meteorological Agency (Figure 2). In addition, daily rainfall data was also collected from the agency in order to analyse the water availability (net rainfall deficit) conditions in the watershed (Figure 7). Dynamically downscaled simulated temperature data from SMHI-RCA4 (RCA4) and CCLcom-CCLM4-8-17 (CCLM) of RCM (Regional Climate Model) climate models in the Coordinated Regional Climate Downscaling Experiment (CORDEX) database were used. Daily temperature data for a control (historical) period (1981–2005) and future period (2006–2055) under RCP4.5 and RCP8.5 scenarios from the African domain with a grid resolution of 0.44 ° x 0.44 ° were downloaded from Earth System Grid Federation (ESGF) databases. For analysis purposes the future time periods were grouped into two time horizons. These are from 2006–2030 (25 years) and from 2031–2055 (25 years), hereafter 2020s and 2040s respectively.

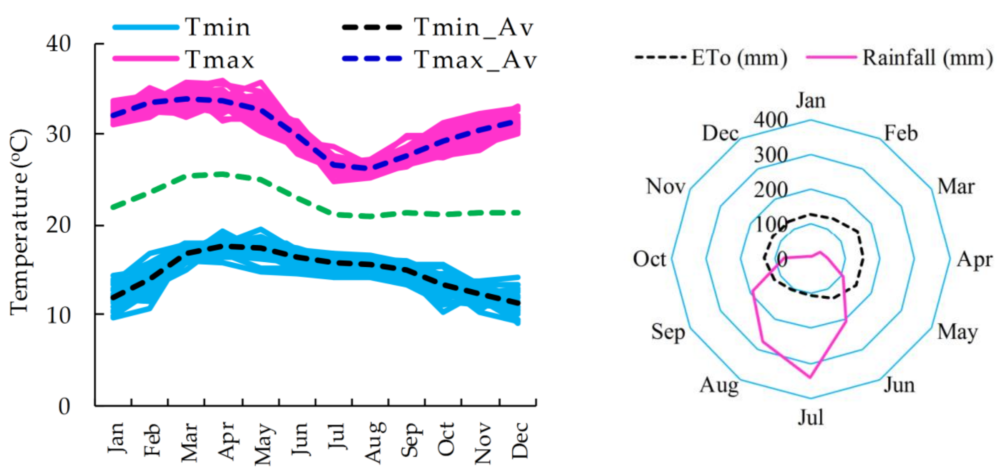

Figure 2. Long-term observed Temperature, Rainfall and ETo for baseline period (1981–2005)

Performance evaluation, calibration and validation of climate models

Climate models simulated data have biases from observations and needs to be downscaled to make them appropriate and applicable at the local scale for impact modelling. There is a wide range of method to perform downscaling of climate models to local level such as dynamic downscaling, statistical downscaling, bias correction (Teutschbein and Seibert, 2012), change factor and quantile perturbation method (QPM). In this study, change factor method was applied to the observed data to transfer climate change signals between the current (control) and future (scenario) climate models run to the measurements as given in equation 1 below (Taye and Willems, 2013). Climate change signal was transformed for both maximum and minimum temperature at monthly time scale.

$$T_{per} = T_{obs} + (T_{sce} - T_{con}) \quad (1)$$

Where:T_{obs} is observed temperature, T_{per} is the perturbed temperature, T_{con} is control period temperature, T_{sce} is scenario period temperature.

Moriasi and others (Moriasi *et al.*, 2015) stated a number of statistical indicators as the performance measures and evaluation criteria for hydrologic and water quality models. In this study four of indicators, namely correlation coefficient (R), coefficient of determination (R^2), root mean square error (RMSE) and Nash Sutcliffe Efficiency (NSE) as given in equation 2 to 5, were used to evaluate the ability of the selected RCM models in recovering observed temperature of Lake Finchaa watershed. The calibration and validation of RCA4 and CCLM of RCM-CORDEX climate models simulations output were performed using 36 years (1981–2016) observed temperature data. Calibration was done using 25 years (1981–2005) data whereas validation was performed using 11 years (2006–2016) minimum and maximum temperature data.

$$R = \frac{\sum_{i=1}^{n}(Obs_i - Obs_{mi}) \times (Sim_i - Sim_{mi})}{\sqrt{\sum_{i=1}^{n}(Obs_i - Obs_{mi})^2 \times \sum_{1=1}^{n}(Sim_i - Sim_{mi})^2}} \quad (2)$$

$$R^2 = \frac{\sum_{i=1}^{n}(Sim_i - Obs_{mi})^2}{\sum_{i=1}^{n}(Obs_i - Obs_{mi})^2} \quad (3)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Obs_i - Sim_i)^2}{n}} \quad (4)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Obs_i - Sim_i)^2}{\sum_{i=1}^{n}(Obs_i - Obs_{mi})^2} \quad (5)$$

Where: $Obs_i$is Observed temperature value (℃), Sim_i is Simulated temperature value (℃), Obs_{mi} is mean of observed temperature value (℃), Sim_{mi} is mean of simulated temperature value (℃) and *n* is number of values

Reference evapotranspiration under current and future climate

Reference Evapotranspiration (ETo) under current climatic conditions was estimated using the FAO Penman-Monteith (FAO-PM) method. Because, this method is recommended as the sole standard method for the definition and calculation of the reference crop evapotranspiration due to its capability of correct prediction of ETo in a wide range of locations and climates. It provides values that are more accurate and consistent with actual crop water use worldwide and it has provisions for calculating ETo in cases where some of the climatic data are missing (Allen *et al.,* 1998). This study used ETo calculator for Windows version 3.2 software to estimate ETo for baseline period according to FAO-PM model as given in equation 6.

$$ET_O = \frac{0.408 \times \Delta(R_n - G) + \gamma \times \frac{900}{T+273} \times u_2 \times (e_s - e_a)}{\Delta + \gamma(1 + 0.34 \times u_2)} \tag{6}$$

Where:ETo is Reference evapotranspiration [mm day^{-1}], Rn is Net radiation at the crop surface [MJ m^{-2} day^{-1}], G is Soil heat flux density [MJ m^{-2} day^{-1}], T is Mean daily air temperature at 2 m height [℃], u_2 is Wind speed at 2 m height [m s^{-1}], es is Saturation vapour pressure [kPa], ea is Actual vapour pressure [kPa], es–ea is Saturation vapour pressure deficit [kPa], Δ is Slope vapor pressure curve [kPa ℃$^{-1}$] and γ is Psychometric constant [kPa ℃$^{-1}$].

Future maximum and minimum temperature projection on a daily basis were done under RCP4.5 and RCP8.5 scenarios to the end of fifth and half decades of 21st century (2055). Projected maximum and minimum temperature were not adequate to estimate ETo using FAO-PM method, hence it requires humidity, wind speed and sunshine hour weather data in addition to temperature data. However, the projected data are adequate to predict ETo using Hargreaves-Samani (H-S) model (Feng *et al.,* 2017; Hargreaves and Samani, 1985) given in equation 7.

$$ETo = 0.0023 \times (T_{\max} - T_{\min})^{0.5} \times (T_{mean} + 17.8)Ra \tag{7}$$

Where: ETo is reference evapotranspiration (mm/day), $T_{max}$is Maximum Daily Temperature (℃), T_{min} is Minimum Daily Temperature (℃), T_{mean} is Average Daily Temperature (℃) and R*a* is Extra-terrestrial radiation (MJm^{-2}/day). R*a* was determined following the procedures given in (Allen *et al.,* 1998).Therefore, future ETo was calculated H-S model and calibrated to FAO-PM model using established regression equation between FAO-PM and H-S model based on current weather data. The regression equation is given in equation 8.

$$y = mx + c \tag{8}$$

Where:*y* is FAO-PM ETo, *x* is H-S ETo and ***m*** and ***c*** are constants representing the slope and intercept of regression equation, respectively.

Results

Estimation of reference evapotranspiration of baseline period

Reference evapotranspiration for a control period (1981–2005) was calculated using both FAO-Penman Monteith (FAO-PM) and Hargreaves-Samani models at daily time scale and arranged in monthly and seasonal time units. The obtained results of FAO-PM model indicated that mean monthly reference evapotranspiration of the study area ranges from 3.39 mm/day (in August) to 5.09 mm/day (in March and April) with an average value of 4.29 mm/day. Monthly mean values of ETo indicated that less variability ($\sigma^2 = 0.33$) and less deviation from mean ($\sigma = 0.575$) of estimated ETo in the Lake Finchaa watershed.

As illustrated in Figure 3 (left), H-S equation overestimated the observed ETo during all months under current climatic condition. Therefore, to calibrate and establish relationship between H-S and FAO-PM models regression analysis was performed. Scatter plot shown in Figure 3 (right) demonstrates the regression equation ($R^2 = 0.95$, m = 0.8886 and c = -0.4596) and the relationship between FAO-PM and H-S ETo models under current climatic condition of the study area. The association between ETo models was strong and positive (R = 0.97). In light of this, the equation was used to estimate ETo values of FAO-PM from H-S model result in the 2020s and 2040s time windows for both CCLM and RCA4 climate models under RCP4.5 and RCP8.5 scenarios.

Projected future temperature

It was pointed out that the input data required for H-S model in estimation of ETo which were maximum and minimum temperature data. Consequently, before proceeding to estimate and examine future ETo, it was necessary to predict future temperature of the study area for the two time horizons and two climate models under RCP4.5 and RCP8.5 scenarios and performance evaluation; transfer of climate change signals to the observed data; and calibration and validation of climate models were carried out in sequence.

Accordingly, both RCM models performance was evaluated using statistical performance indicators mentioned in the previous section. The results show that both climate models are limited in accurately capturing both minimum and maximum temperatures observed in the watershed. Subsequently, biases of the raw simulated data were improved using the change factor downscaling method through extracting climate change signals between raw control and scenario data and applied to observed data. Then, calibration (1981–2005) and validation (2006–2016) of climate models were performed. The performance of each model after bias correction was analysed and evaluated using statistical performance indicators given under materials and methods section of this study. The summary of statistical performance measures of the models at monthly time step are presented in Table 1 for both minimum and maximum temperature.

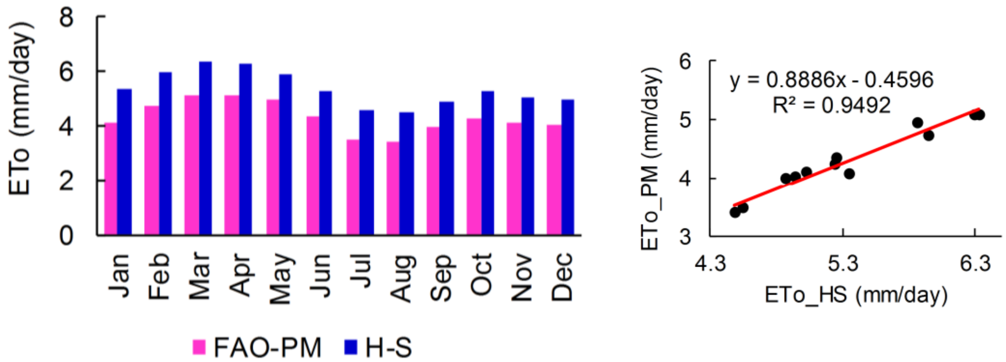

Figure 3. Comparison of monthly ETo values estimated by FAO-PM and H-S models and their correlation

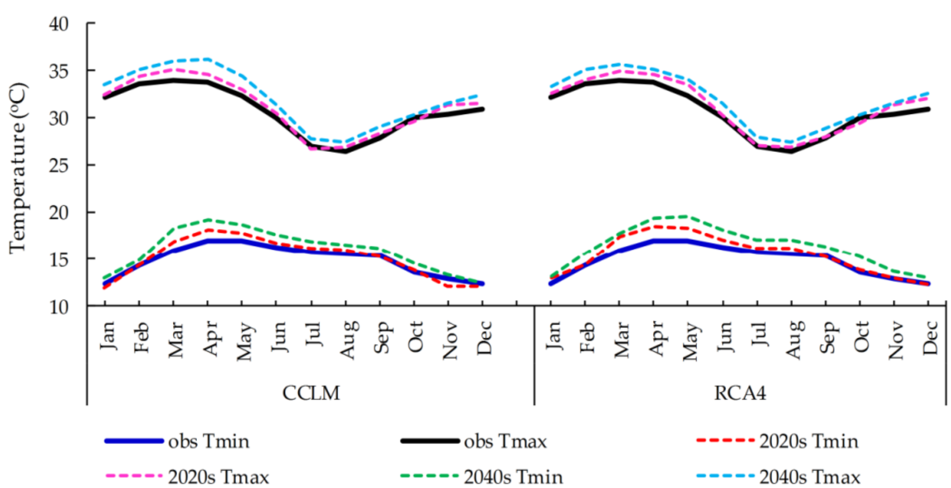

Figure 4. Observed and projected future temperature under different scenarios

Table 1. Performance of climate model in simulating mean monthly maximum and minimum temperature

Statistical Performance Indicators	Climate Model			
	CCLM model		RCA4 model	
	T_{Min}	T_{Max}	T_{Min}	T_{Max}
R	0.88	0.88	0.84	0.88
R^2	0.77	0.78	0.70	0.77
RMSE	1.29	9.59	2.92	5.26
NSE	0.61	-12.43	-0.99	-3.04

The obtained results revealed that both climate change models performed good to very good during calibration and validation period in reproducing observed temperature according Moriasi and his colleagues (Moriasi *et al.,* 2015) recommendation on the performance rating of hydrological models at watershed level.The obtained values of R^2 for both models at monthly time scale ranged between 0.65–0.75 (good range) using minimum and maximum temperature and it was also greater than 0.75 for CCLM model showing very good model fit. So, both models were able to reproduce the temperature of Lake Finchaa watershed supported by better bias correction methods (Figure 4).

The projected future temperature would show an increasing trend under both scenarios. At the end of fifth and half decades of 21st century (2055) in average minimum (maximum) will rise by 0.923 ℃ (1.33 ℃) and 1.12 ℃ (1.41 ℃) in each month under RCP4.5 and RCP8.5 respectively as simulated by CCLM of RCM-CORDEX climate model. Similarly, under RCP4.5 (RCP8.5) scenario in average maximum and minimum temperatures are expected to increase by 1.10 ℃ (1.27 ℃) and 1.14 ℃ (1.48 ℃) in each month respectively as per RCA4 climate model simulation (Figure 4).

Projection of future reference evapotranspiration

Using forecasted temperature ETo was initially estimated by H-S model and later calibrated to FAO-PM model using regression equation developed based on control period ETo. The obtained results show that annual mean ETo value will rise for both climate models (CCLM and RCA4) under both scenarios (RCP4.5 and RCP8.5) in both time horizons (2020s and 2040s). For instance, based on CCLM model simulation, ETo will increase by 1.65% (1.67%) under RCP4.5 (RCP8.5) in the 2020s time slice as compared with baseline period. The maximum percentage of increase in mean annual ETo will be 4.38% (2.77%) under RCP8.5 in 2040s time window for CCLM (RCA4) climate change model. The detail was presented in Table 2.

Seasonal mean ETo values of Finchaa watershed will also be affected by changes in climate signals. The seasonal rate of ETo values are expected to rise by the end of 2055 in Finchaa watershed. Figure 5 shows that there has been a gradual increase of ETo in MAM and ONDJF seasons under both climate change scenarios for CCLM and RCA4 models in both 2020s and 2040s time windows. Seasonal average ETo was projected to rise by 0.22 mm/day, 0.26 mm/day and 0.12 mm/day in ONDJF, MAM and JJAS season respectively. The JJAS season ETo will show the minimum rise relative to MAM and ONDJF seasons in future under both RCP4.5 and RCP8.5 scenarios.

In addition, the result indicated that the mean monthly ETo values are increasing in trend for the considered scenarios, climate models and time windows. For CCLM RCM-CORDEX climate model the highest increase in mean monthly ETo will be 0.33 mm/day in January (0.30 mm/day in January) and 0.41 mm/day in February (0.41 mm/day in January) under RCP4.5 (RCP8.5) for respective time horizon of the 2020s and 2040s. On the other hand, for RCA4 climate model the highest increase of mean monthly ETo will be observed in January month with 0.23 mm/day (0.27 mm/day) and 0.23 mm/day (0.27 mm/day) in the 2020s and 2040s respectively under RCP4.5 (RCP8.5).

The expected maximum drop in mean monthly ETo value is –1.12 mm/day in the 2020s under RCP4.5 scenarios for both CCLM and RCA4 climate models. For RCA4 climate model mean monthly ETo shows slight decrease in May (except at 2040s under RCP4.5), June, September and October, in both time windows and RCPs scenarios. Similar trends will also be observed in May, June, September and October under RCP4.5 and RCP8.5 in the 2020s and in June (under RCP4.5) and October (under RCP8.5) in the 2040s for CCLM climate model.

Table 2. Observed and Projected average annual values of ETo (mm/day) and Increase of percentage (PI)

Climate		**Observed**	**2020s**		**2040s**	
Model	**Scenario**	**ETo**	**ETo**	**PI (%)**	**ETo**	**PI (%)**
CCLM	RCP4.5	4.29	4.36	1.65	4.48	4.42
	RCP8.5	4.29	4.37	1.67	4.48	4.38
RCA4	RCP4.5	4.29	4.33	0.95	4.41	2.68
	RCP8.5	4.29	4.41	2.77	4.41	2.77

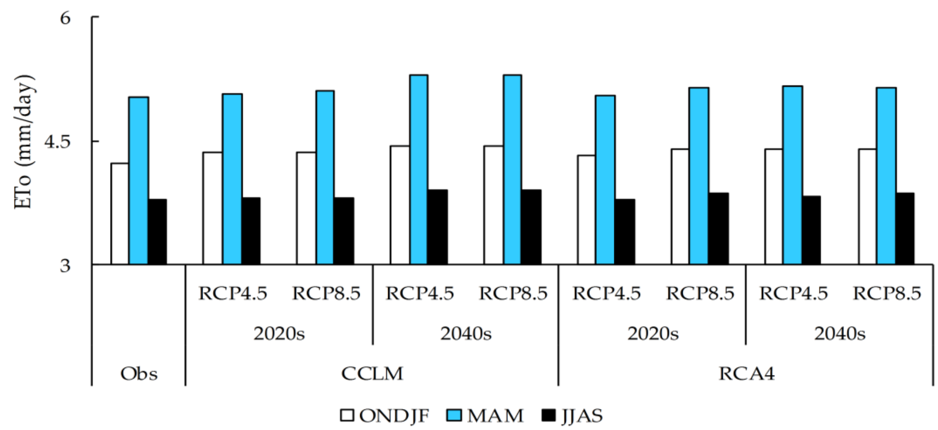

Figure 5. Current and future seasonal average ETo for both scenarios and time window

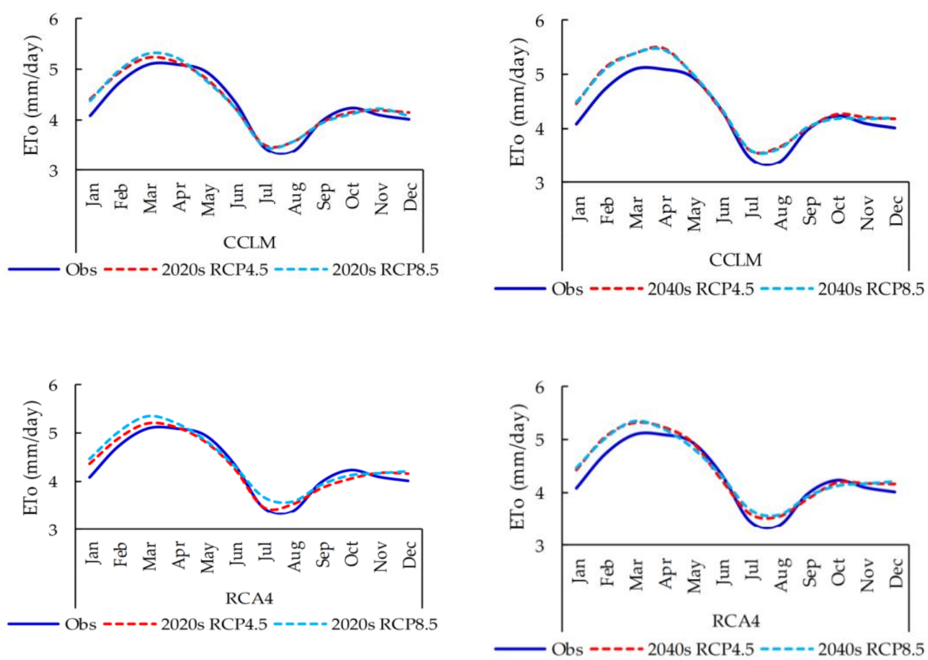

Figure 6. Comparison of current and future mean monthly ETo of Lake Finchaa Watershed under different scenarios

A comparison of the two selected RCM-CORDEX climate models (Figure 6) results revealed that both climate models are in complete agreement in projecting future ETo. For instance, mean monthly ETo shows the highest increase in January month and both models simulations show the rise in mean monthly ETo in July, August, November, December, January, February, March and April months under both scenarios. Again, both models show that mean monthly ETo values of May, June, September and October will slightly decrease in future relative to the baseline period, particularly in 2020s under both scenarios. The selected climate change models simulations results show that the fully consistent outputs which reduce uncertainty of the obtained result and indicate the applicability of both models in forecasting climate change impacts in Finchaa watershed.

Water availability

Furthermore, analysis was performed to predict and indicate future water availability under climate change scenario. Water availability is expressed as the excess or deficit of net rainfall as ETo deducted from. It is also called climatic water balance. This was done using the (2055) highest mean monthly values of ETo of RCM-CORDEX climate models and observed mean monthly rainfall of control period assuming that it will neither increase nor decrease in future. Climatic water balance of the watershed under current and future climate conditions was illustrated in Figure 7.

The obtained result showed that at the end of 2055 total annual net rainfall deficit will increase by –77.93 mm (from –258.27 to –336.2 mm) in Finchaa watershed due to rise in ETo. As shown in Figure 7 (right), even though it does not increase the number of water shortage months, net rainfall deficit is increased throughout all months as compared with the control period monthly deficit. It became more severe if the future rainfall is reduced. Here is, therefore, a point where local and regional water managers are concerned and expected to propose remedial actions.

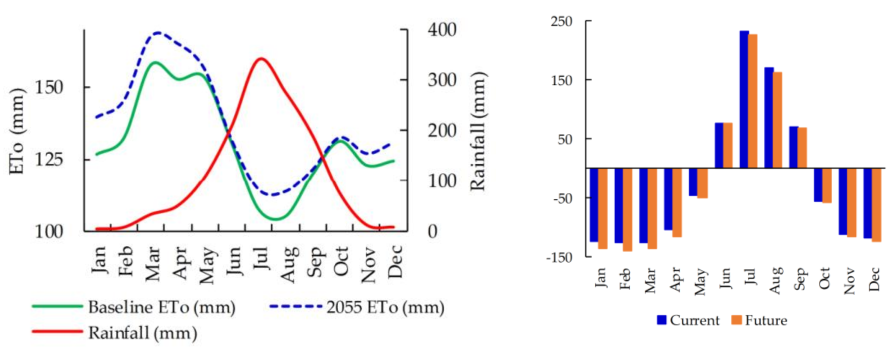

Figure 7. Mean monthly rainfall ETo (left) and Net rainfall for baseline (1981–2005) and scenario (2006–2055) periods (right)

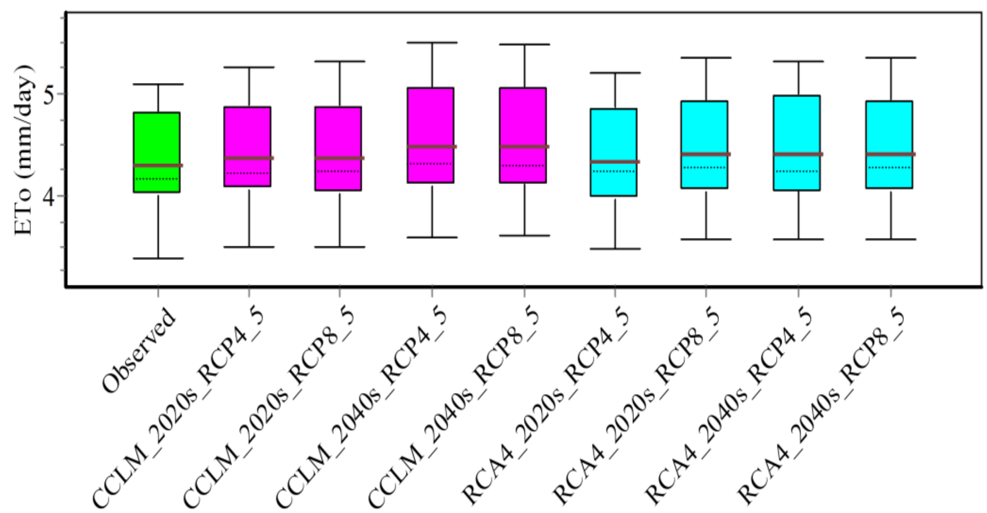

Figure 8. Box plot of Mean monthly ETo (mm/day) of both RCA4 and CCLM models under RCP4.5 and RCP8.5 for 2020s and 2040s time slices

Discussion

Future agro-meteorological variables such as ETo are subjected to the potential impacts of climate change due to human and naturally induced factors. These factors enhance emissions and concentrations of greenhouse gases which are the primary driving factors in rising temperature around the globe. The current study estimated control period ETo using FAO-PM model and projected the future ETo was obtained using H-S model, then converted the equivalent FAO-PM model ETo based on regression equation developed between them for baseline period. The main reason behind this procedure is that less data requirements of H-S model (maximum and minimum temperature only) and recommendation of FAO-PM model as a sole method to forecast ETo due to its ability to in predicting ETo accurately and consistently in a wide range of locations and climates (Allen *et al.*, 1998). And H-S model required temperature data only to estimate ETo.

Statistically, the developed equation has good predictive ability and used to forecast ETo of the 2020s (2006–2030) and 2040s (2031–2055) time windows using CCLM and RCA4 RCM-CORDEX climate models projection output under RCP4.5 and RCP8.5 scenarios. The obtained strong and positive (R = 0.97) correlation between FAO-PM and H-S models indicates good prediction ability of the equations. Similar observation also reported (Ouda *et al.*, 2015). The ability of each of climate model in capturing observed temperature during calibration (1981–2005) and validation (2006–2016) period confirmed the applicability and adequacy of the models dataset in the future in the Finchaa watershed. It is in line with IPCC report (IPCC, 2007) stated that the importance of development of different downscaling methods to maintain the confidence in changes simulated by climate models for the study of regional- and local-scale climate change.

The uprising trend in maximum and minimum temperature was predicted for both models and time horizons. The highest mean monthly increase was forecasted for RCP8.5 for both maximum (+2.4 ℃) and minimum (+2.62 ℃) temperature at the end of 2055 due to the representation highest radiation concentration in RCP8.5 emission scenario. The direction of change of temperature agreed with previous studies (Ayele *et al.*, 2016; Feng *et al.*, 2017; Gebre and Ludwig, 2015; Hulme *et al.*, 2001; IPCC, 2014; Mekonnen and Disse, 2018; Roth *et al.*, 2018; Taye *et al.*, 2011; Taye and Willems, 2013; Worqlul *et al.*, 2018) and slightly differs in magnitude (Roth *et al.*, 2018). This is because of the differences in models resolution, type and numbers as well as time horizons range and scenarios investigated in the studies. Besides, for CCLM RCM-CORDEX climate change model maximum temperature (1.37 ℃) become hotter than minimum temperature (1.03 ℃) which support the finding of previous work in the basin (Geleta and Gobosho, 2018; Taye and Willems, 2013). In contrast, for RCA4 of CORDEX model, change in annual average minimum temperature (1.31 ℃) is higher than maximum temperature (1.19 ℃) which contradicts previous study (Taye and Willems, 2013) this will probably be due to difference in downscaling techniques employed, but it is consistent with previous results of (Ayele *et al.*, 2016; Gebre and Ludwig, 2015; Mekonnen and Disse, 2018; Worqlul *et al.*, 2018) under taken in different sub-basins of Blue Nile basin. As an illustration, this is highly consistent with the range produced in previous work of Gebre *et al.*, 2015; Gebre and Ludwig, 2015; Roth *et al.*, 2018; Taye *et al.*, 2015; Taye and Willems, 2013) undertaken in different sub-basins of the Blue Nile basin. Consistent rising trend of maximum and minimum temperature will be observed in Main Beles and Gilgel Beles sub-basins of Blue Nile (Worqlul *et al.*, 2018). Similar trend also expected in the Didessa sub-basin of Blue Nile basin (Gebre *et al.*, 2015). Average annual maximum and minimum temperature will significantly increases in the future under both RCP4.5 and RCP8.5 scenarios in the Blue Nile (Dibaba *et al.*, 2019; Gebre and Ludwig, 2015; Dibaba *et al.*, 2020).

The obtained results of FAO-PM model indicated that during the baseline period mean monthly reference evapotranspiration of the study area ranges from 3.39 mm/ to 5.09 mm/day with an average value of 4.29 mm/day. This finding strength the previous work of Geleta and his colleagues (Geleta *et al.*, 2019). Projected annual, seasonal and monthly ETo showed to increase the values across the watershed due rise in future temperature. The current study shows that significant increase in annual total ETo of lake Finchaa watershed. The baseline period annual ETo (1567.07 mm) is expected to increase from 14.98 mm (by 0.96%) to 69.38 mm (by 4.43%), with a mean of 41.79 mm (by 2.67%) at the end of 2055 under both RCP4.5 and RCP8.5. This means, in average 417.9 m3 of water per hectare is expected to be lost as evapotranspiration per annum from the watershed in addition to current lose. Figure 8 shows a box plot of mean monthly ETo under both RCP4.5 and RCP8.5. It indicates the comparison of observed and projected mean monthly ETo. It also summarizes minimum, maximum, mean, median and quartile statistics of baseline period and future mean month ETo in 2020s and 2040s for both RCA4 and CCLM climate models of RCM-CORDEX under both selected scenarios.

Consequently, the projected annual arithmetic mean of ETo value highly consistent with the result of (Taye and Willems, 2013) findings. They found that annual ETo can be changed by 3.34% and 5.97% (in average by 4.65%) at the end 2050 in Blue Nile basin using QPM and LARS-WG (Long Ashton Research Station Weather Generator) downscaling methods respectively. It also falls within the range found by Gebre and colleagues (Gebre and Ludwig, 2015) stated as ETo will change by -8% to 12% for the time horizon of 2031–2040 in Didessa sub-basin of Blue Nile basin. The finding of the current also matches with previous investigation in Beles sub-basin of Blue Nile basin of (Worqlul *et al.*, 2018) stated that monthly ETo may increase by 2% and 4.7% in the time windows of 2020–2045 and 2046–2070 respectively. The present findings seem to be consistent with other research (Taye *et al.*, 2011) which found 1–8% rise of ETo in time slice of 2046–2065 in Lake Tana catchment of Blue Nile basin using 17 GCM models. Moreover, it is clear from the above that the mean change in monthly ETo of lake Finchaa watershed is positive, which corroborate the findings of previous works in the Blue Nile basin (Gebre *et al.*, 2015; Taye *et al.*, 2011; Worqlul *et al.*, 2018). However, the findings of the current study do not support the previous research (Ayele *et al.*, 2016) that indicated dry-season ETo change will be reduced in the time horizon of 2021–2040, up to –17% in Gilgel Abbay sub-basin of Upper Blue Nile River basin. This is probably arising from the differences in model uncertainty and location and weather of study area. As well as, the projected seasonal mean ETo values of Finchaa watershed will also be affected by changes in climate signals. The JJAS season ETo will show the minimum rise relative to MAM and ONDJF seasons in future under both RCP4.5 and RCP8.5 scenarios. This result is consistent with the previous work of authors of (Taye *et al.,* 2011). In brief, rate of evapotranspiration is expected to rise due the strong and positive correlation between temperature and evaporation (Ayeleet *et al.,* 2016; Geleta *et al.,* 2019). Rising in temperature is the responsible for change hydrologic components through increasing the rate of reference evapotranspiration in the Blue Nile sub-basins (Worqlul *et al.,* 2018).

Besides, change in future ETo is an indicator of reduction in available water in the watershed for socio-economic development activities and environmental purposes in near future time. The analysis implies that at the end of 2055 total annual net rainfall deficit will be increased by 30.2%. This may become more severe and increase the number of water shortage days—number of days in which the amount of ETo greater than rainfall—if the future dry season rainfall will be reduced as found by the authors of (Ayele *et al.,* 2016).This will affect climatic water balance of the area as net rainfall decreased. It must also be noted that significant increase in ETo in most of months can reduce the portion precipitation going to be infiltrate and percolate to join groundwater table due less time for detention on soil surface. Consequently, the annual river flow is subjected to be reduced at the end of 2055 under increased water demands from different users (Gebre *et al.,* 2015). Reduced flow can give drop in reservoir water levels thereby may decrease power generation potential of Finchaa Hydro-electric power plant (Ayele *et al*., 2016; Daba, 2018). This can result in rising of irrigation water requirement of crops grown in the area due to increase in rate of ETo in most of months. This may aggravate chronic water shortage in the area if the future rainfall is reduced due climate change which needs further investigation. Therefore, proper design of irrigation facilities is mandatory to cope up with the rising of crop water requirement in the future followed by rise in ETo rate (Worqlul *et al.,* 2018). Change in climate will likely to occur that may affect water resources and hydrology of Upper Blue Nile Basin (Mekonnen and Disse, 2018). It also impose pressure on water availability and accessibility particularly in horn of Africa (Ayele *et al.,* 2016).

In conclusion, in the Lake Finchaa watershed temperature is anticipated to be increased by the end of 2055 under both RCP4.5 and RCP8.5 scenarios at monthly, seasonal and annual time scales. It is projected that the mean monthly temperature will rise up to 2.62 ℃. As a result of rise in temperature, the average rate ETo will be increased in the watershed up to 4.42% on annual basis. The highest rise in seasonal average ETo will be observed in MAM season by 0.26 mm/day. The future mean monthly ETo of January and December month will show the largest increase than other months of the year for the period and scenarios under investigation. The precipitation excess will move toward decrease in all months. Consequently, the water requirements of crops grown in the area will be expected to rise in the future. The future water balance of Lake Finchaa may be affected as evaporation rate increases. Furthermore, the annual stream is also expected to decline as there will be reduction in recharge opportunity time for groundwater. Drop in stream flow may have contributed to the decrease in power generation capacity of Finchaa hydro-power station. More analysis of future climate change perturbation impacts on ETo and other agro-meteorological and hydro-climatic variables using additional climate models is vital to further discover the future impacts of climate change in the watershed and to represent different features of the watershed and assess applicability of models to the watershed. Therefore, it is suggested that concerned and interested stakeholders should develop and implement appropriate strategies and measures to forearm the prevailing climate change in the watershed.

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