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Evaluation the Performance of Regional Climate Models in Simulating Rainfall Characteristics over Upper Awash Sub-Basin, Ethiopia

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Abstract
To obtain reliable estimates of the likely impacts of climate change on the hydrological regime in the basin determination of the most appropriate climate model was needed. This study aims to evaluate the performance dynamically downscaled simulations of General Circulation Models (GCMs) by Regional Climate Models (RCMs) over Upper Awash sub-basin. The evaluation is based on how well the RCMs simulate the characteristics of the rainfall pattern in Upper Awash sub-basin for the period of 1985 to 2005. For performance assessment the observed rainfall data was obtained from National Meteorological Agency of Ethiopia. Future climate data from CORDEX Africa was dynamically downscaled and corrected for bias using delta change approach. The models were evaluated using statistical measures such as coefficient of variation (CV), root mean square error (RMSE), correlation coefficient and bias. Findings of this study indicates that the MPI-ES-LR climate model performed best in terms of correlation coefficient and CNRM-CM5 best in terms of coefficient of variations. All models were found best in capturing the observed rainfall, but no individual model is best in all performance measures. The ensemble of models is better in simulating the characteristics of rainfall rather than individual models and best in all performance measures. Therefore, in order to capture different aspects of the basin rainfall it is recommend to use ensemble of models simulations rather than individual model.
Keywords: Climate change, GCM, RCM, Ensemble, Upper Awash
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I. INTRODUCTION

Adverse impacts of climate change may worsen existing social and economic challenges of the whole country, particularly where people are dependent on resources that are sensitive to climate change. Developing country like Ethiopia is vulnerable to climate change since the economy of the country mainly depends on agriculture, which is very sensitive to climate change and variations (Abadi and Kassa, 2014). Among many elements of climatic variables rainfall and temperature are the most common and important for the rural people's livelihoods that depend on rain-fed agriculture. According to IPCC (2014) the precipitation pattern and the temperature will significantly change by the end of 21st century which will affect the hydrologic system. Variability in the hydrological cycle will have effects in the timing and magnitude of runoff, ecosystem dynamics, social and economic systems. The magnitude and spatial distribution of the changes in climatic variables and the characteristics of the area, clearly defines severity of the impacts on water resources at local level. Therefore, climate change assessment studies are important to advance knowledge, to create awareness, to develop adaptive water resources and management plans at sub-basin level (Almsegad and Rjients, 2015).

Currently general circulation models (GCMs) are the most advanced tools available for simulating the response of the global climate system to increased greenhouse gas concentration in the atmosphere (Mutayoba and Kashaigili ,2017). However, GCMs are not capable of capturing the detailed processes associated with regional climate variability and changes (Almsegad and Rjients, 2015). In order to formulate adaptation policies in response to climate change impacts, reliable climate change information is usually require at finer spatial scales. Regional climate models (RCMs) are useful for understanding local climate in regions that have complex topography (Meron *et al*., 2018). However, the reliability of the spatially distributed model output is strongly dependent on the quality of the climate forcing data. Christensen *et al*., (2007) state that one inherent source of uncertainty comes from the RCM's inability to simulate present day climate conditions accurately. Therefore, before using climate model for impact assessment, it is important to evaluate their performance at different spatial scales. This is of the most important for choosing the appropriate climate model to be used for impact assessment since the performance of the models differs from location to location and from one RCM to another. The main objective of this study is to evaluate the performance of the individual Regional Climate Models (RCMs) used in Coordinated Regional Climate Downscaling Experiment (CORDEX) and the ensemble average of the RCMs to simulate the characteristics of the rainfall pattern in Upper Awash sub-basin.

II.MATERIALS AND METHODS

A. Description of the Study area

This study was conducted on the Upper most part of Awash River Basin, which is located between latitude 9° 18‘ N and 8° 17‘ N and longitude 37° 57‘ E and 39° 4‘ E. The sub-basin is located in the western highland part of the basin and covers part of the basin above Hombole, including the capital city Finfinne (Figure 2.1). The areal coverage of the watershed is about 7256 km^2.

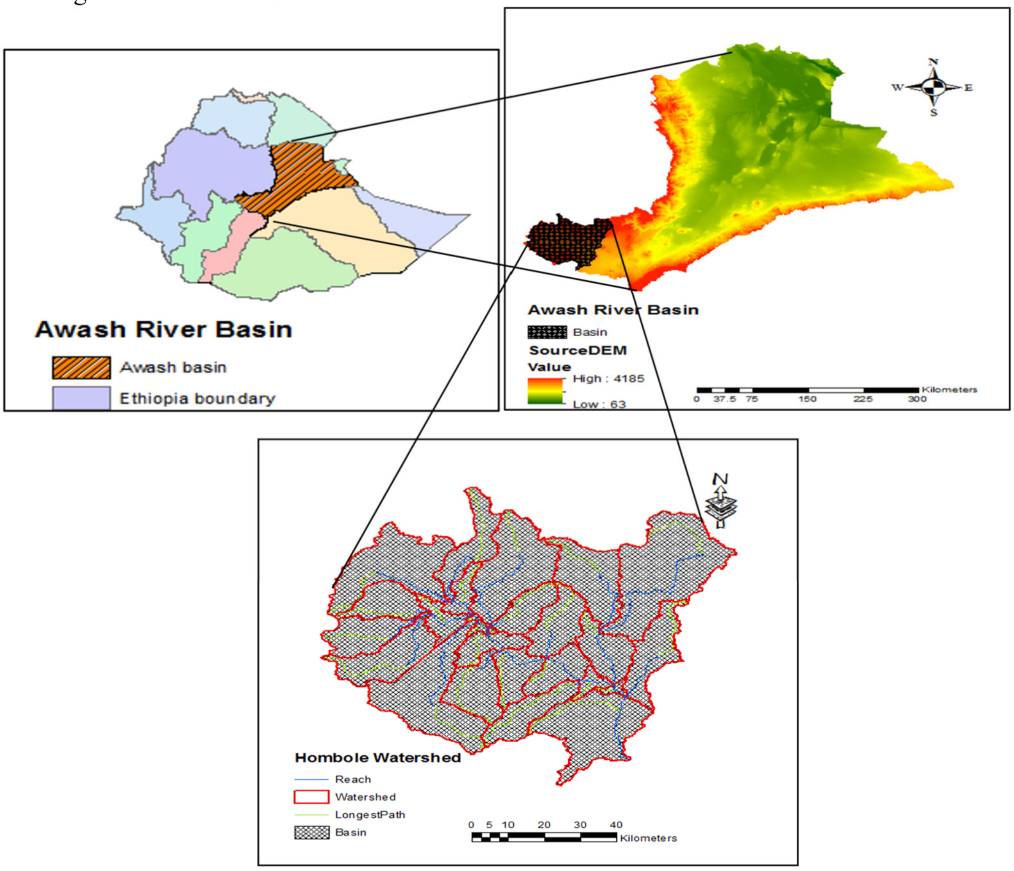

Figure 0 Location of upper Awash sub-basin.

The basin has annual rainfall ranges from 850mm to 1000mm in the plain area and mountains of upper Awash River basin respectively. Mean annual temperature is about 15°C in the highlands and 21°C around the lowlands. The Sub-basin receives approximately 70% -75% of its annual rainfall during the wet season which covers the months June–September (Daba, 2014).

B. Datasets

The daily rainfall data from 6 representative weather stations in the Upper Awash sub- basin were collected from National Meteorological Agency (NMA) of Ethiopia. This study used rainfall simulated data from three regional climate models in the Coordinated Regional Climate Downscaling Experiment (CORDEX) database. These data were obtained from http://cordexesg.dmi.dk/esgf-web-fe/. Rainfall data for the period from 1985-2005 are used to compare with model simulation over the Upper Awash sub-basin.

C. Areal Rainfall Analysis

The area weighted average method was used to calculate the average rainfall from the CORDEX RCMs received by the entire catchment. The weighing area of recorded rainfall station was done by Thiessen polygon method using Arc GIS Version 10.4.1 to investigate areal contribution of each station (Figure2.2). The areal average rainfall P of the entire area A derived from n stations and calculated as:

$$P_{ave} = \frac{P_1A_1+P_2A_2+ P_3A_3+\cdots+P_nA_n}{A_1+A_2+A_3+\cdots+ A_n} \quad (1)$$

Where, P_1, P_2 and P_n are rainfall recorded by the stations 1, 2 and 3 respectively and A1, A2 and A3 are respective areas of the Thiessen polygon and n is the number of stations.

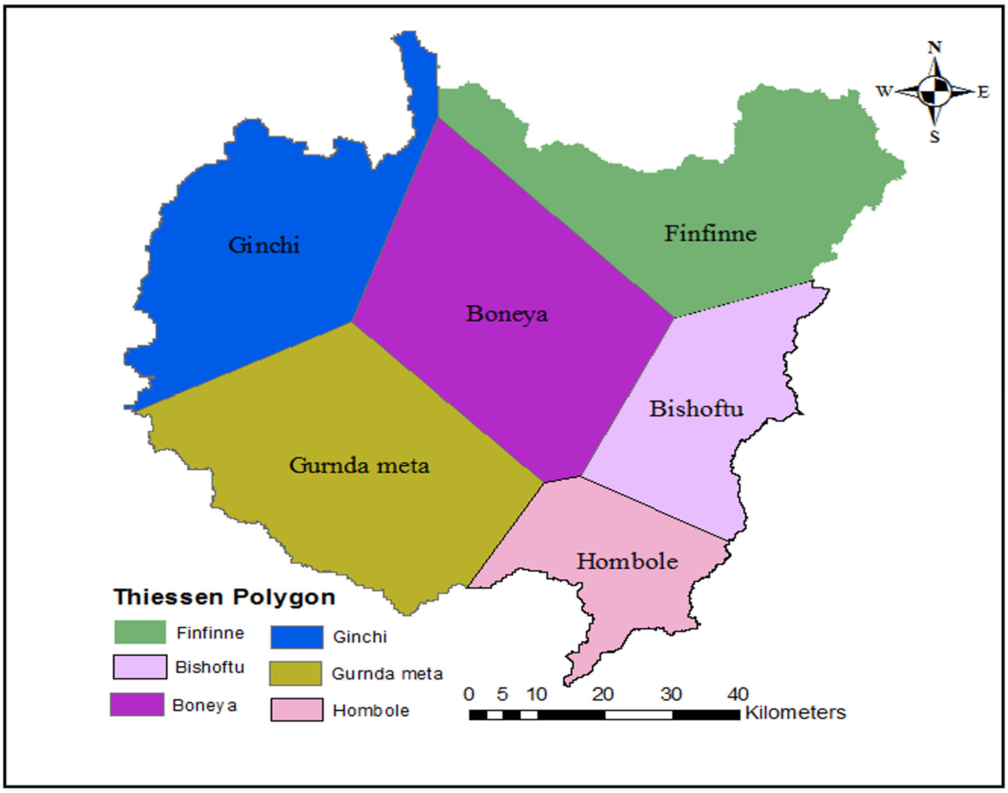

Figure 2.2 Thiessen polygons for upper Awash sub basin

D. Performance Evaluation of climate models

Different models have their own strengths and weaknesses (Endris *et al.,* 2013). The performance of each model was evaluated against observation. An ensemble of the models was also computed and its performance evaluated together with the models against the observation. The climate data of high resolution regional climate models obtained from CORDEX-Africa database was used. Outputs from models were evaluated against observations using some of the statistical measures recommended by the World Meteorological Organization (WMO). The statistical measures include bias, root mean square error, coefficient of variation and correlation coefficient.

$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{N}(\text{Fi} - \text{Oi}) \quad (2)$$

$$\text{RMSE}=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(\text{Fi} - \text{Oi})^2} \quad (3)$$

$$\text{Correl} = \frac{\sum_{i=1}^{N}(\text{Fi}-\text{Fmean})(\text{Oi}-\text{Omean})}{\sqrt{\sum_{i=1}^{N}\text{Oi}-\text{Omean})^2}\sqrt{\sum_{i=0}^{N}(\text{Fi}-\text{Fmean})^2}} \quad (4)$$

Where, F and O are the simulated and observed values respectively, while *i* refer to the simulated and observed pairs and N is the total number of such pairs.

E. Bias Correction for Climate Models

Bias correction is usually needed as climate models often provide biased representations of observed times series due to systematic model errors caused by imperfect conceptualization, discretization and spatial averaging within grid cells. It was applied to compensate for any tendency to overestimate or underestimate the mean of downscaled variables. For this study Delta change method was used for post processing and bias correction of RCMs output for further impact analysis. The delta-change approach is an alternative to the direct use of RCM simulations and it is one of the most widely and commonly used correction methods for RCMs scenarios of future conditions for climate change impact studies (Shabalova*et al*., 2003, Sahilu and Nigussie, 2016). The average monthly rainfall is corrected to match the average monthly rainfall for 20 years (1985-2005). The formulas used for rainfall bias correction are indicated in Equations 5 and 6, respectively.

$$p_{bc} = P_p\frac{P_o}{P_r} \quad (5)$$

$$T_{bc} = T_P + T_o - T_r \quad (6)$$

Where, P_{bc} is Bias corrected future rainfall amount in mm:

P_P is predicted future rainfall amount in mm;

P_o is mean of observed rainfall amount in mm:
Pr is mean of computed historical rainfall during the observation period in mm.
T_{bc} is Bias corrected future temperature in ^{0}C;
T_p is predicted future temperature in ^{0}C;
T_o is mean of observed temperature in ^{0}C;
T_r is mean of computed historical temperature during the observed period in ^{0}C.

III. RESULTS AND DISCUSSION

A. Bias Correction for Data obtained from Climate Model

The outputs of the raw RCMs underestimate and overestimate the mean monthly rainfall as compared to areal precipitation. These outputs are adequately corrected by delta change method for rainfall and temperature (delta change multiplicative for rainfall and delta change additive for temperature). The simulation result of the long term mean monthly rainfall of the observed and the outputs of the RCM within the base period showed good agreement (Figure 3.1). This implies that the bias corrected output of the model is well capturing and representative of the study area.

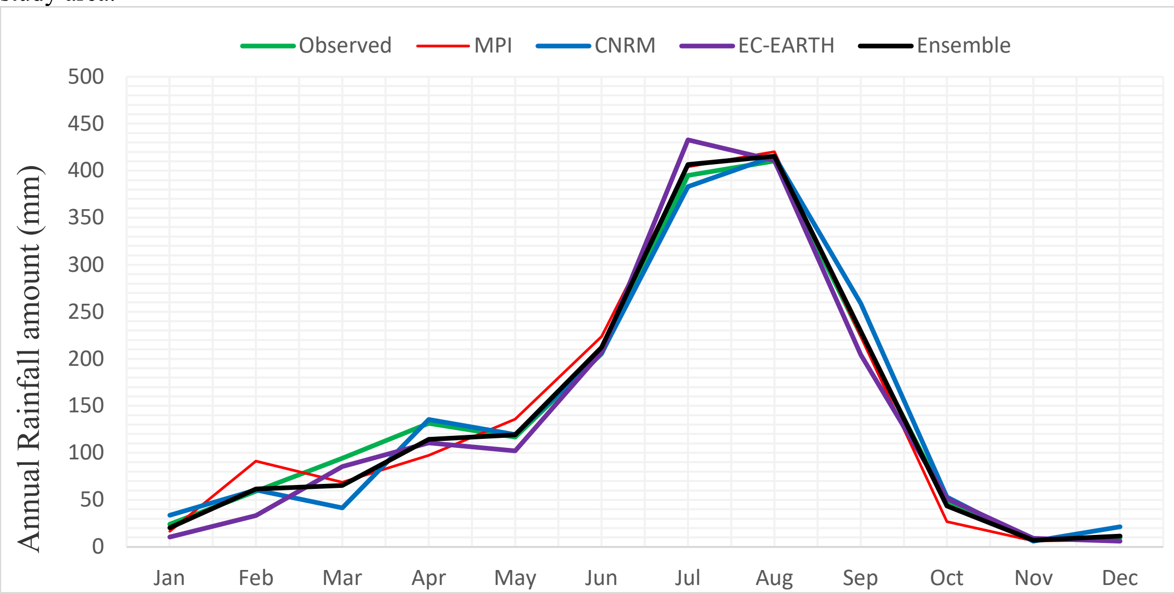

Figure 3.1Dynamically downscaled climate model simulations and gauged rainfall data at monthly based for Upper Awash sub basin

B.Performance evaluation of climate model against observed data

Coefficient of variation, root mean square error, correlation coefficient and bias were used in the evaluation of the performance of the three models and their average in relation to the observed data. The performance measures are statistically based and the results of individual performance measures method for annual total rainfall over the Upper Awash sub-basin are shown in table 3.1.

Table 3.1 Performance of RCMs in simulating mean annual rainfall over Upper Awash sub basin

	Annual rainfall(mm)	Bias (%)	CV (%)	RMSE (mm/year)	Correlation
Observed	987.17	-	11.5	-	-
MPI-ESM-LR	984	-12.52	13.1	225.04	0.96
CNRM-CM5	1091.13	47.05	11.2	228.36	0.92
EC-EARTH	950.71	-38.62	9.24	236.28	0.91
Ensemble	1008.61	-7.88	11.18	129.57	0.994

When the correlation value is +ve, it denotes a positive linear relationship and if it is -ve, it denotes a negative linear relationship. In the results, all models showed a positive relation while CNRM-CM5 and EC-EARTH indicated low correlation than MPI-ESM-LR and Ensemble. Using the correlation analysis method MPI and ensemble had the best data set which performed well against the observed. Bias shows large differences with the largest bias of 47.05% for CNRM-CM5 and -38.32 for EC-EARTH which suggests the presence of a systematic error as large as half of the annual rainfall amount. The smallest bias of -7.88% is shown for ENSEMBLE which suggests that basin wide rainfall is well captured and represented. Almsegad and Rientjes (2015) also concluded that biases of the models can be considered relatively large with values larger than ±10%. When comparing the gauged mean annual rainfall to model based there exists differences showing overestimation 1091.13 mm for

CNRM-CM5 and underestimation at 950.71 mm for EC-EARTH. For RMSE performance measure, ensemble has the smallest value 129.57mm per year whereas EC-EARTH resulted in the largest value 236.28 mm per year. MPI-ES-LR performed best when evaluated in terms of rainfall correlation coefficient between observed and simulated and also CNRM-CM5 indicated best in terms of coefficient of variations. All models were found best in capturing the observed rainfall. However, no individual model is best in all performance measures and the Ensemble of models is better to simulate the rainfall rather than individual models.

IV. CONCLUSION

In this study, the performance of CORDEX regional climate models in simulating the rainfall characteristics over upper Awash sub-basin was evaluated. Dynamically downscaling method were used to downscale the projected rainfall data from three GCMs driving models. Statistical measures of model performance that include the bias, root mean square error, correlation coefficient and coefficient of variation are used. Comparison between rainfall data from CORDEX RCMs and observed was done to test the ability of the CORDEX RCMs to reproduce the annual cycles of rainfall. It is found that the CORDEX RCMs and the ensemble average reproduce the annual and annual cycles of rainfall over upper Awash sub-basin. The ensemble of the models reproduces better the magnitude of rainfall compared with the individual models. Generally, the ensemble mean of all the models presents better results when compared with the observation. However, no individual model is best in all performance measures and the ensemble of models is better to simulate the rainfall characteristics rather than individual models.

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