Global Scientific JOURNALS

GSJ: Volume 10, Issue 4, April 2022, Online: ISSN 2320-9186
www.globalscientificjournal.com

Impacts Of Climate Change On rainfall In The Didesa River Catchment, Western Ethiopia

Melkamu DiribaUjulu (a)

National Meteorological Agency, Benishangul Gumuz Meteorological service center, Assosa, Ethiopia (email:melkamu.diriba2007@yahoo.com)

Gemechu Raga Osana (b)

National Meteorological Agency, Western Oromia Meteorological service center, Jimma, Ethiopia (email:gemechuraga@gmail.com)

ARTICLE INFO

Key words

Catchment

Climate change

Didesa

ABSTRACT

Recently, the Coordinated Regional Climate Downscaling Experiment (CORDEX) initiative has made multiple Regional Climate Models' (RCMs') outputs available for end users across the African continent. But their accuracy has to be evaluated before running climate simulations in impact studies. Therefore, in this study the impact of climate change projections on rainfall over the Didesa catchment of Abay basin were evaluated using three independent regional climate model. The performance of all models was assessed based on their bias, Root Mean Squared Error (RMSE), and Coefficient of Variation (CV). Findings of this study indicated that the annual rainfall bias of the models varies between -21.9% and 15%, suggesting high variation. Based on the finding, climate change studies may benefit from the use of multi model simulation. Biases of most of the models proved that correction for the systematic error of RCM outputs must be made before the model outputs could be utilized by users. Compared to the base line period, all the models indicated that the total annualrainfall increases in midterm period (2021-2050) and long term (2051-2080) as projected under the RCP4.5. In long-term periods, climate models predicted that a decrease in rainfall in all seasons of the year except for summer season under RCP8.5 scenario, where as rainfall is predicted to increase when compared to the base line period. The overall conclusion of the study is that Didesa catchment of Abay basin is likely to experience more flow in the future than baseline period .

Contribution/Originality: This study is our original work for contribution to the understanding of the effect of climate change issues especially that of rainfall for the benefit of future planning activities of the study area.

1. INTRODUCTION

Weather is the state of the atmosphere at a given time while climate is the average weather over a period of time (Thorpe, 2005). The Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5) has shown an increase of 0.85°C in the global mean temperature since 1880 until 2012 (IPCC, 2013). These changes in global temperature have accompanied by changes in climate patterns and systems in different ways (Feng et al., 2014). Many regions have experienced changes in rainfall leading to frequent occurrence of floods (Min et al., 2008) or droughts, otherwise (Dai, 2011). These changes in climate system will have strong impact on local and regional hydrological regimes in many regions of the world (Hu et al., 2013).

According to Tadege (2007), the current climate variability is already imposing a significant challenge to Ethiopia by affecting food security, water and energy supply, poverty reduction and sustainable development efforts, as well as by causing natural resource degradation and natural disasters. Therefore, assessing the impact of climate change on its rainfall such as of Didesa river catchment can provide important information to be considered in development plans in water resources, agriculture and to overcome the impacts of intensifying recurrent droughts. This gives an opportunity to plan appropriate climate change adaptation strategies that must be taken ahead of time based on the projected rainfall.

Several studies have attempted to evaluate the impacts of climate change in Ethiopia (Beyene et al., 2010; Abdo et al., 2009; Belay, 2011). However, none of these studies use ENSEMBLE model predictions, which provide mean of forecasting robust simulations for weather and climate prediction uncertainties. Particularly, no impact assessment of climate change study had been performed for the Didesa catchment, despite some studies on other parts of the Abay basin (Abdo et al., 2009). Therefore, this study aimed at assessing the impact of climate change on the rainfall of Didesa river catchment and generated essential input information that can assist for the effort in managing the catchment.

2. Data AND Mthodology

2.1. Description of the study area

The study was conducted in Didesa river catchment (Figure 1) which is geographically located between 07^{o}40'N and 10^{o}00'N, and 35^{o}30'E and 37^{o}15'E. The elevation of the catchment ranges between 612 and 3200 meter above sea level. The catchment drains in to four Zones in Oromiya National Regional State (Jima, Illubabor, East Wollega, and West Wollega) as well as Benishangul Regional State. Didesa river catchment, which is the largest tributary of Abay, contributes roughly a quarter of the total flow of Abay (Timketa, A., 2016).

GSJ: Volume 10, Issue 4, April 2022
ISSN 2320-9186

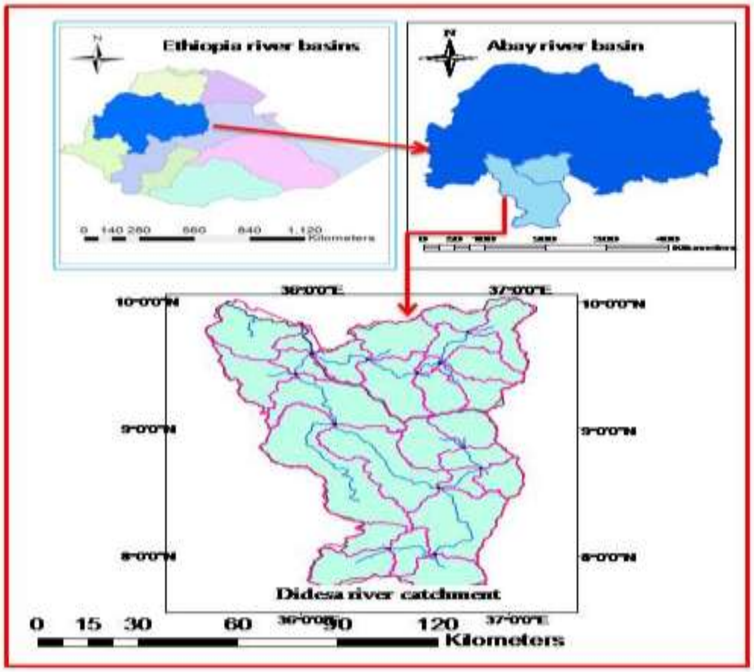

Figure 1.Map of the study area

2.3. Data availability and analysis

Meteorological data were collected from number of stations of National meteorology agency (Figure 2).The most important time series data necessary for this research was long years rainfall under area of the study.

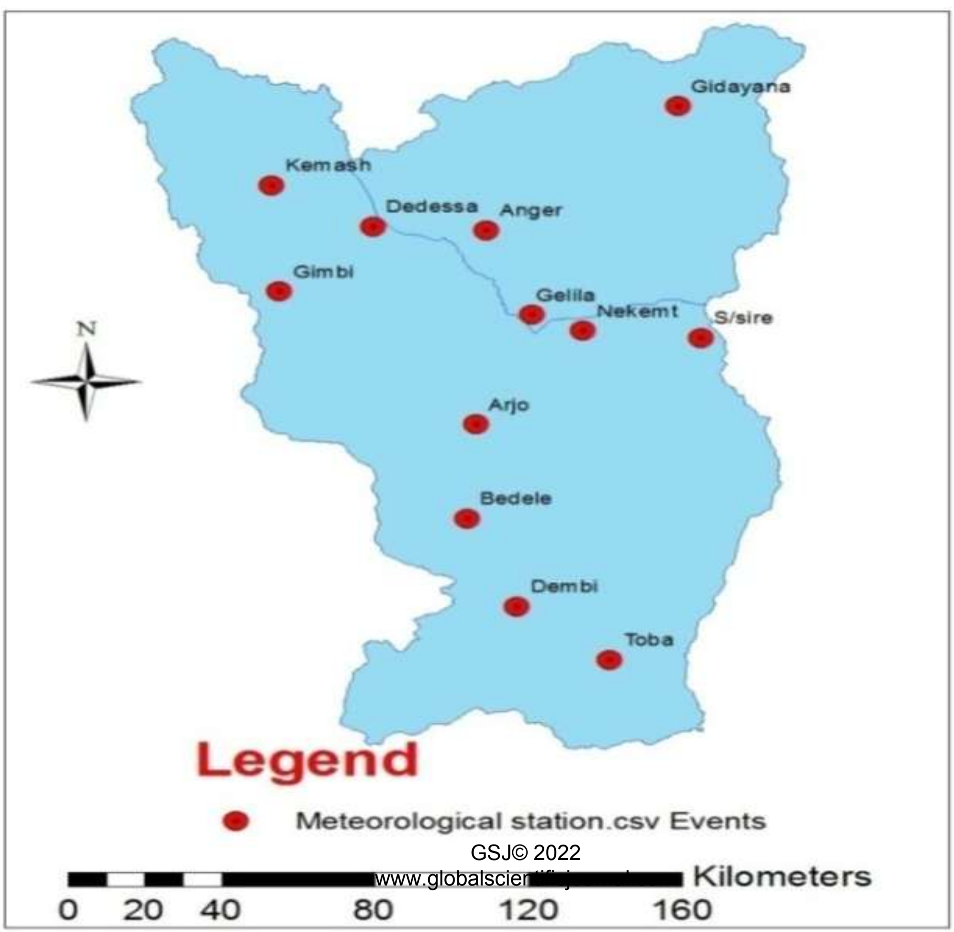

Figure 2. Selected weather stations of Didesa river catchment

2.3.1. Quality and consistency check of rainfall data

Homogeneity test on station-based climate data

The consistency and homogeneity of rainfall data from individual stations were evaluated. Homogeneity for some stations were tested by computing non-dimensional of rainfall data by dividing the monthly time series data and averaged rainfall amount of the respective year (FigureA:3).

$P_i = (\bar{P}_i / P)*100$ ………………………………………………………………………… (1)

Where:-

Pi = Non dimensional value of rainfall for month i

P = Monthly time series average

$\bar{P}_i$ = Over years averaged monthly rainfall of the station and plotted to compare the stations included in to compare the stations include in the computation of rainfall with each other

2.3.2. Estimation of areal total rainfall of the catchment

In order to achieve accurate estimation of the spatial distribution of rainfall, the Thiessen polygon method was considered (Allen et al., 1989). The method weighs each gauge in direct proportion to the area it represents of the total basin without consideration of topography or other basin physical characteristics. Station weights are scalar factors used to transform point rainfall observed at this rainfall gauging stations into an associated mean rainfall over an area that the station data are assumed to represent. The area represented by each gauge is assumed to be that which is closer to it than to any other gauge (Table 1). If there are n stations with rainfall value P_1, P_2, P_3….P_n and A_1, A_2, A_3,….A_n are the area of the respective Thiessen polygons, the average rainfall over the catchment P_{av} is computed as

$$P_{av}=P_1A_1+P_1A_2+P_1A_3\ldots P_nA_n/\ (A_1+A_2+A_3+\ldots A_n) \qquad \ldots\ldots (2)$$

Where: - $P_iA_i/\ A_i$ = weight factor for each station

Table1. Rainfall stations and their corresponding area

No	Station name	Area in km^2	% area of covered
1	Anger	2481.67	8.31
2	Arjo	2748.40	9.20
3	Bedele	2976.30	9.96
4	Dembi	2520.15	8.44
5	Didessa	2342.98	7.84
6	Gelila	2183.36	7.31
7	Gidayana	3236.45	10.83
8	Gimbi	2342.99	7.84
9	Kemash	2677.23	8.96
10	Nekemt	2047.17	6.85
11	S/sire	1844.03	6.17
12	Toba	2473.52	8.28

2.4.3. Data processing in the RCMs

For climate change data processing the following steps were used.

1. The first step was downloading simulated daily amounts of rainfall from CORDEX project at spatial grid resolution of 0.44 degree (~50 Km)

2. The second step was extracting the RCM overlapping grids that fall into the study area for the selected gauging stations from step one. Then, basin average climate model time series data was calculated using area weighted average.

3. The third and final step was calculating the biases for the historical and future scenarios. In this step the bias correction is for daily rainfall data.

Bias correction procedures employ a transformation algorithm for adjusting RCM output. The underlying idea is the identification of possible biases between observed and simulated climate variables, which is the basis for correcting both control and scenario RCM runs. Bias correction methods are assumed to be stationary, i.e., the correction algorithm and its parameterization for current climate conditions are also valid for future conditions. The following bias correction methods to adjust RCM simulations was used that is linear scaling approach which defined as equation 3 below.

$P_{cor}= P_{unc} * P_{obs},c_{tr}/P_{rcm},ctr$ and …..……………………………………………..………….. (3)

Where P_{cor} is corrected rainfall, P_{unc} is uncorrected rainfall, $P_{obs,ctr}$ and $P_{rcm,ctr}$ are the mean value of observed and simulated rainfall.

3. RESULTS AND DISCUSSIONS

3.1. Evaluation of the regional climate models simulation

3.1.1. Annual rainfall amount

We first compared basin mean annual rainfall amount of Didesa river catchment as obtained from gauged data and model. A 30 year mean annual rainfall (i.e.in the period of 1989 – 2018), gauged, rainfall amount by Thiessen areal rainfall computations was 1719.88 mm. When comparing the gauged mean annual rainfall to model counterparts (Table 3), there exist large differences showing over estimation as large as 1990.93 mm (15.76%) but also under estimation at 1343 mm (21.91%) for respective RCMs. It can be seen that all the models except CNRM model underestimated the observed Didesa river catchment annual rainfall amount.

Also simulation bias showed large differences with the largest bias (-21.29%) for MPI (Max Planck Institute) which suggests the presence of a systematic error is less than a quarter of the annual rainfall amount. The smallest bias (-9.13%) was shown for ENSEMBLE which suggests that basin wide rainfall is well captured and represented. For standard error mean, ENSENBLE model has the smallest value (6.2mm)whereas EC-EARH resulted in the largest value (8.23mm) which implies the result varies from model to model (Table 2) because of their characteristics.

Overall, we could say that the climate models tend to underestimate real observations in the inter-annual rainfall variability. However, this under estimation is only by less than 3.5%. In terms of bias and standard error of mean, the ENSENBL of models performed best whereas the EC_EARTH model performed poorest (Table 2). This also supported by the results of correlation coefficient where almost all correlations were greater than 0.58 for all models, suggesting that outputs of the models well matched the observations at annual base (Table 2).

This result is consistent with the conclusions by Alemseged and Tom (2015), indicating the annual base correlation coefficient values in model MPI cannot be considered as high even though some models can performance good at the Upper Abay basin.

The study showed that for Didesa river catchment the bias of the ENSEMBLE mean rainfall amount is lower than that of the three models. However, it underestimated the observed mean annual rainfall amount by almost 10%. As compared to most individual models the ENSEMBLE can capture the rainfall variability. The low CV of the ENSEMBLE mean rainfall (16.5%) suggests that variability is suppressed as compared to all separate models.

Further, using ENSEMBLE mean led to somewhat reduced standard error of mean of 6.2mm which is smaller than that of the separate models. Generally, as can be stated by (Kim et al., 2014) the ENSEMBLE mean of simulated rainfall is often to result in better accuracy than using simulations of individual models. Likewise the ENSEMBLE mean result indicates a better accuracy than using simulations of individual models.

Table2. Performance of the CORDEX-RCM simulations in capturing and representing mean annual rainfall over the Didesa river catchment over the period 1989–2018

	Mean annual rainfall (mm)	**Bias (%)**	**CV (%)**	**Standard error of mean(mm)**	**Correlation (-)**
Gauged	1720	-	19.7	8.49	-
CNRM	1990	15.15	16.8	7.78	0.75
EC_EARTH	1343	-21.89	25.5	8.23	0.63
MPI	1354	-21.27	18.1	6.89	0.58
ENSEMBLE	1563	-9.13	16.5	6.2	0.78

3.1.2. Evaluation of corrected rainfall

The daily bias corrections between the observed and simulated variables during the control period for each RCM models were applied. The bias correction was done on RCM-simulated rainfall. The linear scaling approach method was used for the ten extracted nearby grids. Figure 3 illustrated linear scaling of the grids extraction. Results showed that for rainfall, the linear scaling method significantly corrects the biased raw RCM; and for those ten extracted grids. Therefore, when we compared here using all stations grid the frequency-based statistics of observed, RCM-simulated (raw) and corrected rainfall data (Figure 3).The results showed that the raw RCM simulation deviates from observation data, with over and underestimation of all the statistics.

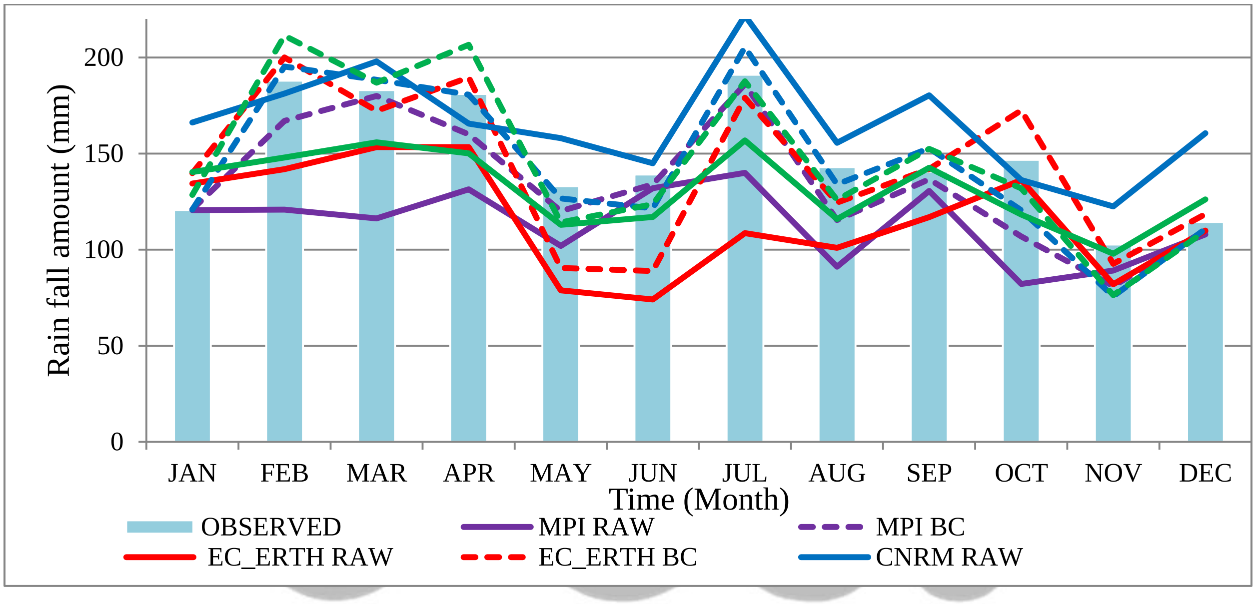

Figure3. Long term mean monthly historical bias corrected and bias uncorrected areal rainfall stations plot at Didesa river catchment

The models capture the observation after correction than the raw RCMs. Thus, the bias correction methods improve the raw RCM-simulated rainfall.

3.2. Seasonal and annual rainfall anomalies

In order to investigate the changes in mean seasonal and annual areal rainfall of the catchment, the statistical analysis were made on rainfall patterns for each season in Ethiopia. Under current study the seasons were classified into four. These are: summer (June-August), autumn (September-November), winter (December-February) and spring (March-May).

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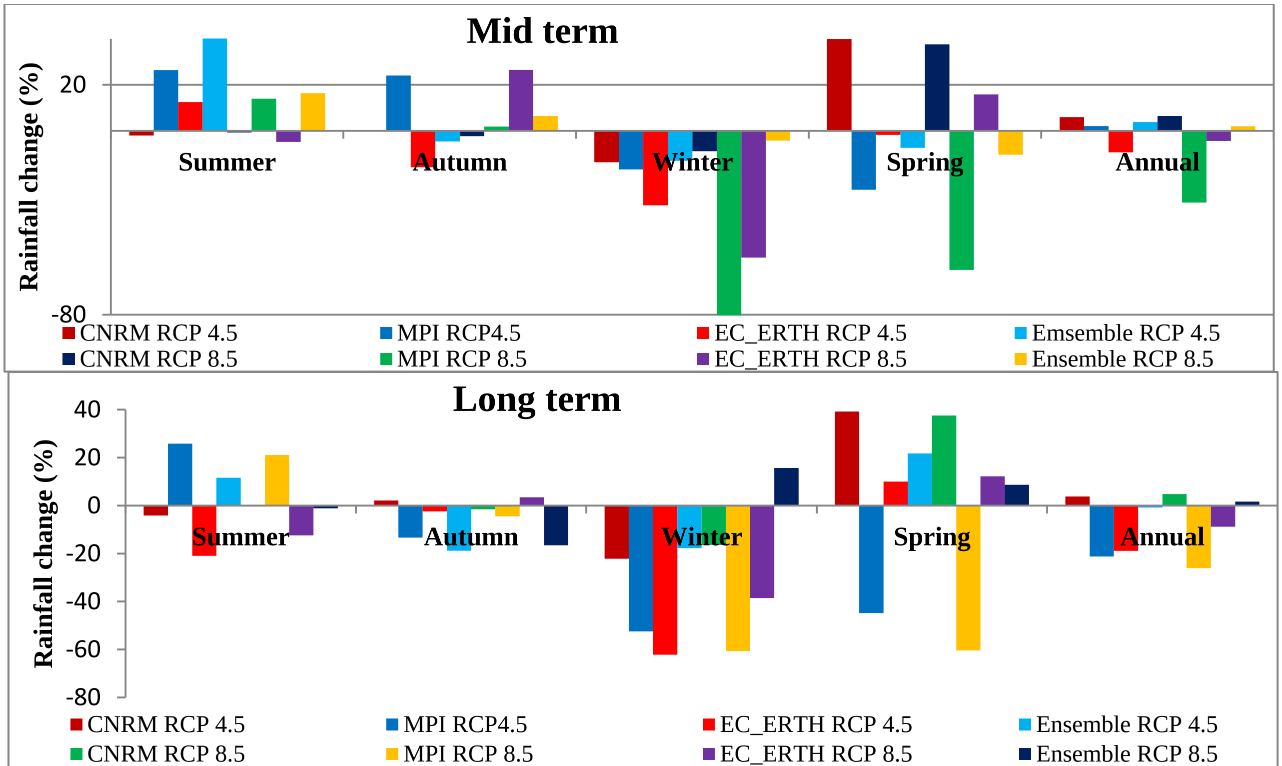

Figure8. Anomalies of bias corrected mean seasonal and annual rainfall in the mid-term (2021-2050) and long term future (2051-2080) periods

The areal rainfall total of the catchment was calculated by developing Thiessen polygon using 12 meteorological stations. Accordingly, the areal rainfall from observed and all projected rainfall for the mid-term and long-term averaged and compared with observed results. The anomalies of bias corrected mean annual and seasonal rainfall and temperature over the entire Didesa river catchment during the future periods of 2021-2051 and 2051-2080 were presented in Figure 8.

Figure 8 illustrates that among all the RCMs, MPI model projected the largest decrease in mean annual rainfall under RCP 8.5 scenario in the mid-term period (-31.23%) and in long-term period (-26.1%). In contrast, the model EC_ERTH projects the smallest decrease in mean annual rainfall (-18.9%) under RCP4.5 scenario in the long term period. On the other hand, the largest increase in mean annual rainfall was projected under model CNRM (+6.44%) with RCP8.5

scenario in the mid-term period. In particular, a decrease of mean annual rainfall in both future periods' ranges from -8.83% to -31.23% when computed over the gauging stations under all models for the respective future periods. In mid-term period projected an average increase of +3.79% under CNRM RCP4.5 and +2% under CNRM RCP8.5.

In long term period projected an increase of +3.76% under CNRM RCP4.5 and an increase of +4.79 % under CNRM RCP8.5. The result showed that the percentage change of the mean annual rainfall in Didesa river catchment in mid-term and long-term periods and indication for increasing trend despite the fact that few models projected a declining annual rain fall. Looking at the seasonal temporal scale, all RCMs projects an increasing rainfall trend in some seasons and a decreasing trend in other season under both scenarios of RCP4.5 and RCP8.5 with respect to the control period of 1989-2018 (Figure 8).

During the spring season under RCP4.5 scenario in the mid future period only one of the model CNRM (39.90%) projects increase in mean seasonal rainfall which is in agreement with the results presented by (Abdela2013) on Gilgal Gibeibe III catchment. The researcher indicated that there is an increase in the projected precipitation while two models and ENSEMBLE i.e. MPI, EC_ERTH and RCM ENSEMBLE mean predicted reduction in mean seasonal rainfall ranging (-8.43% to -58.93%) . Under RCP 8.5 scenario also model CNRM projected an increase in mean seasonal rainfall by (+6.44%) while MPI, EC_ERTH and RCM ENSEMBLE mean predicts a decrease in seasonal rainfall. In the long term period, during the spring season all the RCMs and the ENSEMLE predicts a decrease in mean seasonal rainfall in both scenarios that ranges from -8.43% to -58.93% and -4.39% to -35.40% under RCP 4.5 and RCP 8.5 scenarios, respectively.

During winter season under both RCP4.5 and RCP 8.5 scenario in the mid future period only on CNRM RCP8.5 and EC_ERTH RCP8.5 models projected an increase in mean seasonal rainfall of (+37.62%) and (+15.8) respectively, while rest of the models and ENSEMBLE mean predicts the decrease in mean seasonal rainfall (ranging from -7.41% to -93.43% in mean seasonal rainfall in both scenarios. During autumn season under RCP4.5 scenario only MPI shows increase of (+0.73%) and under RCP8.5 scenario MPI (+1.87%) and EC_ERTH (+26.52%) in the mid future period where as rest of the models and their ENSEMBLE decreasing ranging from (-0.3% to -9.17%) and (-2.29% to -6.88%) under RCP4.5 and RCP8.5 scenarios, respectively. During summer season- under RCP4.5 scenario in the midterm period only MPI model shows an increase by (+19.79%) whereas all models and their Ensemble predicts decrease in mean seasonal rainfall ranging (-0.81% to -2.0%). Under RCP8.5 scenario only one model CNRM shows decreasing by (-0.69%) whereas all models and their ENSEMBLE predicts an increase in seasonal rainfall ranging (+4.79% to +15.19%).

On the long period, under RCP4.5 and RCP 8.5 only model CNRM predicts an increase in mean seasonal rainfall of (+25.80%) and (+21.09%) respectively, whereas all models and their ENSENBL predict a decrease of rainfall ranging (-4.13% to -20.97%) under RCP4.5 and (-0.41% to 17.59%) under RCP8.5.

From the above result it can be seen that among the seasons spring Season distinguished as the largest decrease in mean seasonal rain fall during the midterm periods under RCP4.5 and RCP8.5 scenario in most of the models which shows time shift of rainfall this result is differ with the work by Abdela (2013) on the basin, whereas winter season distinguished as the largest decrease in mean seasonal rain fall during the long term periods under RCP4.5 and RCP8.5 scenario in most of the models. In summer season, an increase in mean seasonal rainfall is predicted in all

Models with very few exceptions under RCP8.5 scenario and decrease under RCP4.5 during the mid-term period.

3.3. Conclusions

It was found that as compared to the base line period, the ENSEMBLE mean from the models indicated that annual rainfall totals was projected to increase more during the midterm term period (2021-2050) than the long term (2051-2080) as projected under both scenarios. In general relative to the baseline period, the annual rainfall amounts over the Didesa river catchment are projected to increase both during the midterm and long term future periods under RCP4.5 and RCP8.5 scenarios.

3.4. Recommendations

1. The observed uncertainty associated with inter-model variability across GCMs when a single RCM is used for downscaling reduced spread in the results of the rainfall. This emphasizes the importance of using the CORDEX-Africa multi-GCM/multi-RCM in order to assess the robustness of the climate change signal and, possibly, to identify and quantify the many sources of uncertainty.
2. This study indicates that there exists a difference in the result found between RCPs in one RCM used. So that, further analysis should be undertaken with Multi RCM with more RCPs and more bias correction method so as to give a clear picture about the result.

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